Oceanic In-Trail Climb Full Mission Simulation Experiment Plan and Results

In-Trail Climb Experimentation Working Group

July 1995

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16. Abstract

This document describes the experiment plan and test results from an In-Trail Climb (ITC) end-to-end simulation study. This study was conducted by the National Simulation Capability ITC Experimentation Working Group at the Federal Aviation Administration (FAA) Technical Center. The ITC procedure was developed by the Traffic Alert and Collision Avoidance System (TCAS) Separation Assistance Working Group. The procedure enables an aircraft, traveling in oceanic non-radar controlled airspace, to climb through the altitude of an aircraft ahead when positive lead aircraft identification and separation distance can be established using TCAS. End-to-end simulations were conducted at the FAA Technical Center utilizing the Oceanic Development Facility and the Reconfigurable Cockpit Simulator. Simulation participants included two flight crews from Delta and United Airlines, two FAA oceanic controllers, and an Aeronautical Radio, Inc. radio operator. The end-to-end simulation consisted of one scenario, with six individual conditions, involving eastbound and westbound tracks in Pacific oceanic airspace. Flight crews used a checklist derived from ITC Training Bulletins as a guide to evaluate the applicability of the maneuver.

FAA, airline, and industry observers present at the test considered the simulation to be a success. As a result of the simulation, the proposed training guide was updated. Conclusions reached from this effort indicate that real time, human-in-the-loop simulations, with flight crews and controllers, are effective for the evaluation of proposed procedures. The scenarios tested demonstrated that the ITC procedure is safe and ready for approval, as assessed in the simulated conditions described in this study. Further testing of the procedure in live flight trials is recommended.

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This document represents the results of a fast-paced effort to validate a new procedure for use in oceanic airspace. This procedure will yield significant airspace user benefit as soon as it is approved and available for operational use.

We acknowledge the tremendous efforts put forth by a small team of individuals who made the In-Trail Climb (ITC) Full Mission Simulation a success. This core team represents the National Simulation Capability (NSC) ITC Experimentation Working Group (EWG). Operating under the direction of Bill Blake (ARD-100), Federal Aviation Administration (FAA) Headquarters, and Paula Nouragas (ACD-350), FAA Technical Center, the team prepared for this simulation in less than 6 weeks, all the while competing with other projects for Technical Center resources (lab space, personnel, and computer time). Some of the members of this team were also part of the FAA Separation and Assistance Working Group's ITC Working Group. This core team included Bill Blake (ARD-100); Paula Nouragas and Diena Seeger (ACD-350); Al Rehmann and Pocholo Bravo (ACD-320); and Joe Miller and Dave Gwartney (Seagull Technology).

We would also like to acknowledge the efforts of other individuals who participated in the study, including: Ken Peppard (ASC-200); Frank Sweeney (ATP-140); Dan McGovern and Debbie McFadden (ACD-330); Albert Macias (ACD-350); George Chang (AFS-430); Harry Nutter (Delta Airlines [DAL] Principal Operations Inspector [POI]); DAL flight crew; Ed Sasman (United Airlines [UAL] POI); UAL flight crew; Brian Wilkie, Rick Coles, Dorothy Bowker, Otto Smith and George Rowand (CTA); Ed Kozicki (Aeronautical Radio, Inc.); Bill Johannes (Oakland National Air Traffic Controllers Association Representative); and Charles Bennett and Steve Fabella (Oakland Air Route Traffic Control Center controllers).

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EXECUTIVE SUMMARY

This document details the experiment plan and test analysis results from an In-Trail Climb (ITC) end-to-end simulation study. This study was conducted by the National Simulation Capability ITC Experimentation Working Group at the Federal Aviation Administration (FAA) Technical Center.

The ITC procedure was developed by the Traffic Alert and Collision Avoidance (TCAS) Separation Assistance Working Group ITC subgroup, a cooperative effort of the FAA, airlines, industry, government laboratories, and FAA technical support contractors. This procedure allows an aircraft to climb through the altitude of another, nearby aircraft that is ahead on the same oceanic track in non-radar airspace. This climb is permitted to occur when positive lead traffic identification and separation distance can be established, using TCAS. The overall ITC program objectives were to design, develop, test, validate, and implement an ITC procedure for operational use by August 1994.

Prior to the end-to-end simulation, part task simulation studies employing high fidelity flight simulators at United Airlines (UAL), Delta Airlines (DAL), and the FAA Mike Monroney Aeronautical Center, were conducted. These studies provided initial data for the evaluation and validation of the procedure. Based on these findings, the end-to-end simulation was designed to incorporate the air traffic control (ATC) functions and additional procedures to further investigate the ITC procedure.

On March 17 and 18, 1994, an end-to-end simulation was conducted at the FAA Technical Center utilizing the Oceanic Development Facility (ODF), including the Oceanic Display and Planning System and the Reconfigurable Cockpit Simulator (RCS). Simulation participants included two flight crews from DAL and UAL, two Oakland Air Route Traffic Control Center oceanic controllers, and an Aeronautical Radio Inc. operator. Principal Operations Inspectors (POIs) from DAL and UAL, and an FAA Air Traffic Procedures (ATP) specialist participated as evaluators for the ITC procedure. Additional support was provided by observers from the FAA Flight Standards Office, the National Air Traffic Controllers Association (NATCA), and the human factors SAE-G10 committee.

The end-to-end simulation exercised one scenario consisting of six individual conditions, involving eastbound and westbound tracks in the Pacific oceanic airspace. The scenario contained approximately 30 simulated aircraft, 3 of which were represented by the RCS and associated aircraft simulators. Oceanic controllers located in the ODF managed the traffic, while flight crews in the RCS piloted the emulated 747-400 aircraft. Each condition incorporated an ITC maneuver and required flight crew and controller evaluations. Flight crews were instructed to use a check list derived from ITC Training Bulletins to evaluate the applicability of the maneuver.

The ATP evaluator viewed the ITC end-to-end simulation as a success and favorable comments were received from the NATCA observer. As a result of the simulation, the proposed training guide was updated. It was agreed that a key word must be defined for use by both the flight crew and controllers to differentiate between a normal climb clearance and an ITC climb clearance.

Additionally, a special annotation to the flight strip denoting the ITC request/clearance was identified. Both the ATP evaluator and NATCA observer viewed the procedure as a beneficial tool for ATC use and supported the initiation of flight trials.

The POIs and flight crews viewed the ITC procedure as inherently safe, though some observations were made. The POIs noted some deficiencies in crew performance, including an occasional failure to perform all steps of the maneuver in the proper order, and confusion about the phraseology used between the controller and flight crews. Flight crews also indicated some confusion about contingency procedures under emergency situations. Recommendations to enhance the flight crew training material resulted from post-simulation debriefing sessions. These included: 1) provision of a procedure card included with the checklist cards containing contingency steps for abnormal situations; 2) addition of a one-page summary of the ATC training materials, including a controller checklist; and 3) creation of an optional informational video. Both the POIs and flight crews recommended proceeding to flight trials.

The conditions tested demonstrated that the ITC procedure is safe and ready for approval, pending the outcome of the flight trials. Conclusions reached from this effort indicate that real-time, human in-the-loop simulations, with flight crews and controllers, are advantageous for testing proposed procedures.

1. INTRODUCTION.

The oceanic In-Trail Climb (ITC) procedure was developed by the Traffic Alert and Collision Avoidance System (TCAS) Separation Assistance Working Group. This was a cooperative effort of the Federal Aviation Administration (FAA), airlines, industry, government laboratories, and FAA contractors. The National Simulation Capability (NSC) program was responsible for the development and execution of the ITC Full Mission Simulation Experiment.

1.1 BACKGROUND.

Oceanic ITC is a procedure that allows an aircraft to climb through the altitude of another nearby aircraft that is ahead on the same oceanic track in non-radar airspace. Currently, this is not permitted because such a climb would violate the same-altitude separation requirements used for most oceanic tracks. In many cases, the result is that the climb aircraft is not permitted to fly an efficient altitude profile. The lead aircraft prevents the climb aircraft from completing a series of step climbs as fuel is burned and the climb aircraft becomes lighter.

The ITC procedure is based on an initial, TCAS-derived range separating the two aircraft. TCAS is not used to monitor the separation of the two aircraft during the maneuver. Existing air traffic control (ATC) procedures are used to ensure separation. More information on the ITC procedure development can be found in Cieplak (1994a, b), and Dillard (1994). ITC Applicability Rules and Air Crew and Controller Procedures are found in appendix A.

1.2 PURPOSE.

The purpose of the NSC's ITC Full Mission Simulation Experiment was to validate the ITC procedure through a realistic end-to-end test. The NSC simulation was unique in that it included an air traffic controller working in a realistic Air Route Traffic Control Center (ARTCC) environment. Several representative conditions were emulated to ensure the procedure was safe and met with the approval of Flight Standards, Air Traffic, pilot representatives, and controllers.

1.3 OVERALL OBJECTIVES.

The overall objectives of the NSC ITC experiments were to:

a. Validate the ITC procedure by allowing Flight Standards and Air Traffic evaluators to review the procedure in a realistic environment and under a variety of flight conditions.

b. Demonstrate that the procedure is safe and practical in today's oceanic environment and that the procedure is ready for flight trials.

c. Demonstrate the validity of the ITC simulation test bed models and procedures by involving controllers and pilots in reviews, shakedown testing, and formal testing.

d. Evaluate human factors issues of the ITC procedure, including safety and workload. Specifically, evaluate if the controller can process the ITC requests in a timely manner.

1.4 APPROACH.

A full mission, end-to-end simulation was developed to test and validate the ITC operational procedure. The term end-to-end describes experimental conditions where all participants in the operational systems are represented as realistically as possible in the simulation. For ITC, this included the controller, the pilot, and the Aeronautical Radio, Inc. (ARINC) operator.

Six ITC conditions were developed to provide a wide range of representative situations under which the procedure could be conducted. These are described in detail in section 2.3.5. The simulation experiment was not intended to provide a large statistical sample of data. Rather, it demonstrated the simplicity and practicality of the procedure in a realistic environment so that flight trials could proceed.

2. SIMULATION DESIGN.

This section defines the objective, approach, simulation methodology, and analysis used for the ITC experiment.

2.1 SIMULATION DESIGN OBJECTIVE.

The overall objective of this simulation was to verify the validity and safety of the ITC procedure using realistic environments for the controller, pilot, and ARINC operator.

2.2 SIMULATION DESIGN APPROACH.

The design approach provided the controller and pilot with realistic environments and workloads as a basis for evaluating the ITC procedure. The following elements were included:

a. Implementation of realistic environments for the controller and pilot in terms of surroundings, functionality of equipment, and workload. This included the Oceanic Development Facility (ODF), the Oceanic Display and Planning System (ODAPS), and the Reconfigurable Cockpit Simulator (RCS).

b. Implementation of detailed, realistic tests which spanned the range of nominal and extreme operational ITC conditions.

c. Assurance of ITC simulation test bed environment and procedure realism by conducting reviews and simulations with the participation of expert controllers and pilots.

d. Design of data collection methods that allowed the evaluation of human factors issues associated with the ITC procedure, including safety and workload.

2.3 SIMULATION DESIGN METHODOLOGY.

The simulation was carried out in the ODF and the RCS, both of which are located at the FAA Technical Center.

2.3.1 ODF Laboratory Configuration.

The ODF was developed to provide a complete oceanic ATC environment to support realistic testing and evaluation of oceanic ATC equipment, interfaces, and procedures. The configuration of the ODF

laboratory included one complete oceanic control position consisting of M1 consoles (with flight strip bays and overhead sector charts), integrated Flight Data Input/Output (FDIO) equipment, voice communication equipment, a flight strip printer, and an emulated ARINC printer. Only one ODAPS Plan View Display (PVD) was used in the simulation. (This was in accordance with normal operating procedures for Oakland ARTCC oceanic control.)

The physical environment of the ODF (as shown in figure 1) realistically simulated the Oakland ARTCC. Supporting ARINC communications were also provided. The ODF's remote operator (RO) engaged in voice and data communication with controllers, and effectively acted as an ARINC operator who relayed voice messages between controllers and pilots. The RO also emulated the roles of controllers in adjacent Flight Information Regions (FIRs) and controllers in other sectors or ARTCCs.

The ODF target generator (TG) provided simulated aircraft flight plans (with corresponding PVD targets) and generated position reports. The position reports reflected the effects of simulated forecast winds, controller clearances, and on-line adjustments made by the RO (who acted as the pilot for the simulated non-RCS aircraft).

The TG accepted scenario data provided by the user. The data were obtained by recording actual operations via System Analysis and Recording (SAR) tapes. For the ITC experiment, flight plans were derived from SAR tape data in order to create several ITC conditions. The test director developed planned event data (such as position reports and altitude change requests) interleaved with aircraft waypoint crossings and associated an expected simulation time with each element in the list.

The ATC environment was fully instrumented to support the collection of controller performance data (including video, audio, and data recording).

2.3.2 ODAPS.

Associated with the ODF was a fully operational ODAPS. ODAPS provides oceanic flight data processing and oceanic display capabilities for selected domestic ARTCCs that have oceanic control responsibilities. ODAPS processes flight plan data and related messages in conjunction with stored adaptation data to produce outputs to be transmitted to FDIO equipment located at the oceanic sector positions. The FDIO equipment uses the data from ODAPS to print flight strips and other messages essential to oceanic ATC. ODAPS also provides oceanic controllers with a graphical representation of the flight plan extrapolated position of all aircraft under ATC on the PVD.

2.3.3 RCS.

The ITC experiment used the RCS (a medium-fidelity flight simulator) to represent the climb aircraft. It was configured as a "heavy" aircraft (either a Boeing 747 or a McDonnell Douglas DC-10). Computer graphics workstations simulated the out-of-the-window view and created realistic displays of aircraft instrumentation. The cockpit included aircraft seats, instrument panels, throttles, a mode control panel, avionics displays, and Flight Management System (FMS) Command Display Units (CDUs).

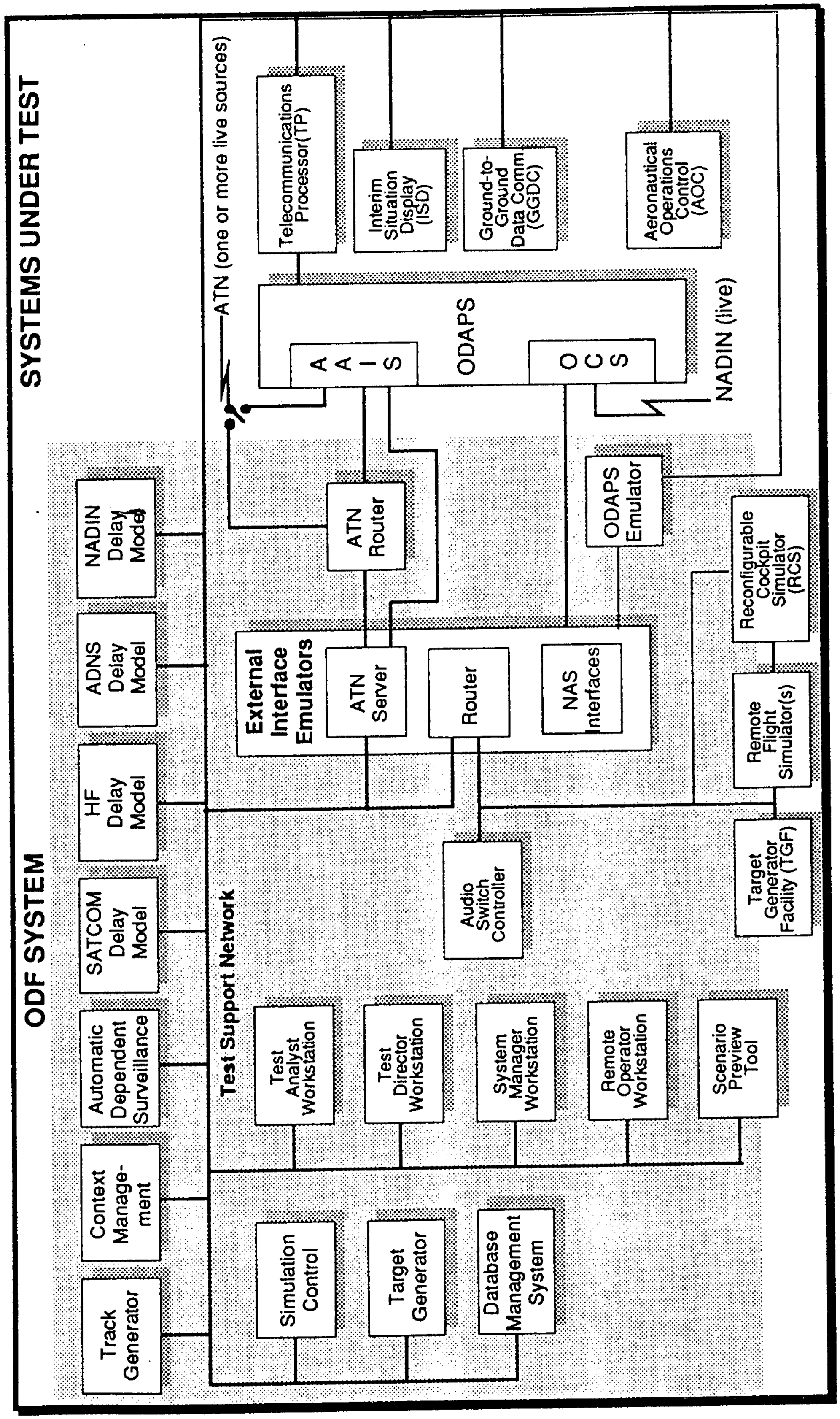

FIGURE 1. ODF CONFIGURATION DIAGRAM

A key element for the ITC simulation was the navigation display. This display showed the route, waypoints, compass heading, and several other features related to aircraft navigation. In addition, it also incorporated TCAS data. Traffic aircraft symbols were presented as white diamonds labeled with relative or absolute altitude. TCAS was used by pilots during the ITC to determine the key parameters for a safe ITC maneuver.

For this simulation, the RCS was linked to the ODF via simulated High Frequency (HF) and Very High Frequency (VHF) radio communications. The simulation used phone lines linking audio equipment in both locations to allow the RCS pilots to communicate with the ODF and the lead aircraft. The pilot had the ability to select either radio.

The second aircraft required for the ITC simulation was the lead aircraft that flew straight and level, preventing the trailing aircraft from climbing. This aircraft was simulated by a second, simplified "desktop" RCS (another computer graphics workstation). There was no simulated physical cockpit for this station, but all critical RCS flight displays were present. A pseudopilot sat at the second RCS and acted as the pilot of the lead aircraft, communicating with the climb aircraft's pilot via simulated VHF radio communications and with the ARINC operator via simulated HF radio communications.

2.3.4 Simulation Participants.

The test participants in the ITC simulation included airline pilots, observers, and official evaluators for United Airlines (UAL) and Delta Airlines (DAL) in the RCS. In the ODF, the participants were active, qualified controllers and controller observers. The simulation participants included:

a. An RCS and an ODF coordinator.

b. Two currently certified oceanic controllers from Oakland ARTCC (who rotated through the controller position approximately every 1 1/2 hours).

c. Two crews of two line pilots each, one crew from DAL and the other from UAL.

d. One ARINC operator staffing the RO position, with assistance from contract personnel.

e. Two FAA representatives trained to observe and record performance data on the controllers working the sectors.

f. Principal Operations Inspectors (POIs) for DAL and UAL acting as evaluators in the RCS cockpit.

g. One Flight Standards representative (AFS-430) acting as an observer in the RCS.

h. Additional support staff provided by ACD-320, ACD-330, ACD-350, and contract personnel at the FAA Technical Center.

2.3.5 Scenario Description.

This section defines the six conditions that were used in the ITC scenario. Table 1 summarizes the most important parameters of the ITC conditions.

TABLE 1. SIMULATION CONDITIONS SUMMARY

Scenario Number	Scenario Name	Closure Rate (Kt)	Initial Range (nmi)	Start Time (sim*)	Flight IDs	Speeds Lead/ Trail**	Altitudes Lead/ Trail***	Expected Duration (min)	Comments
1	Nominal Case	0	21	1:30	DAL161 DAL151	M.85/488 M.86/498	FL350 FL330	20	Nominal conditions. Expect clearance to be granted and procedure executed without incident.
2	Interfering Traffic	0	25	2:00	DAL15 DAL25 NWA355	M.83/483 M.84/498 M.85/483	FL330 FL310 FL350	10	Interfering traffic above and behind requesting aircraft, at the target final altitude, out of TCAS range. Expect clearance to be denied.
3	Mis-identified traffic	0	21	2:20	UAL118 UAL184	M.84/483 M.85/493	FL360 FL340	20	Requesting pilot identifies wrong aircraft. Expect controller to catch mistake and deny or ask for confirmation.
4	Assigned Mach too high	.03 Mach	18	2:50	DAL94 DAL84	M.80/463 M.83/485	FL340 FL320	10	Speed differential (based on assigned mach) outside of bounds. Expect controller to deny clearance or adjust speeds.
5	Unable to climb	30	18	3:20	UAL815 UAL825	M.83/480 M.86/500	FL350 FL330	20	Aircraft close in on each other during artificially long delay in communications. Expect that requesting aircraft either adjusts speed or declines clearance once granted.
6	Lead Aircraft Engine Out	0	18	3:40	UAL100 UAL192	M.83/483 M.84/491	FL340 FL320	20	Worst case scenario. Engine failure on lead aircraft just after ITC climb begins. Expect lead aircraft to follow normal emergency rules (turn off route, descend) without loss of separation.

* Simulation
** Mach number and true airspeed
*** FL = Flight Level (hundreds of feet)

In the table and the descriptions, the two participating aircraft are referred to as the climb aircraft and the lead aircraft. The climb aircraft requested and performed the ITC; it started below and behind the lead aircraft. The lead aircraft blocked the ascent of the climb aircraft and appeared as a TCAS target on the climb aircraft's TCAS display.

Each of the six conditions constituted a different ITC situation. This was accomplished by starting with actual flight data derived from an Oakland ARTCC SAR tape and modifying the aircraft positions along the routes to create typical ITC situations. A typical situation was where one aircraft was ready to climb but was prevented from doing so by another aircraft at the next higher flight level (2000 feet).

Six of these ITC situations were created at various locations in the Pacific Ocean. Most encounters were on routes between Hawaii and the US west coast. One event was on a route between Los Angeles and Sydney, Australia. Figure 2 is a map of the Pacific Ocean showing the locations of the ITC conditions.

The ITC scenario ran for a total of 3 1/2 hours. During this time, the full RCS and the desktop RCS acted as the ITC aircraft in six, 30-minute ITC conditions. In this way, a variety of situation types were tested in a single, continuous air traffic simulation run. The procedure consisted of a series of communications between the pilots of the lead and climb aircraft and between the climb aircraft and the oceanic air traffic controller, via the ARINC operator. The steps in the procedure were as follows:

a. The climb aircraft made an initial contact with the lead aircraft via VHF radio. The identity, location, closure rate, and altitude of both aircraft were established. The climb aircraft communicated its intention to conduct an ITC maneuver. Each aircraft was visible on the other aircraft's TCAS display.

b. To confirm the identity of the lead aircraft, the climb aircraft requested that the lead aircraft switch its transponder to "standby," and then back on again. This had the effect of changing the symbol for the lead aircraft on the climb aircraft's TCAS screen.

c. The climb aircraft contacted Oakland ARTCC (via ARINC) and requested an ITC.

d. Oakland ARTCC evaluated the request (against specific ITC criteria) and granted permission (via ARINC) for the climb aircraft to commence the ITC maneuver.

e. The climb aircraft initiated the ITC (using TCAS to establish separation) and notified Oakland ARTCC upon reaching its new assigned altitude.

(A sample script of the type of communications used in the ITC experiment is presented in appendix B.)

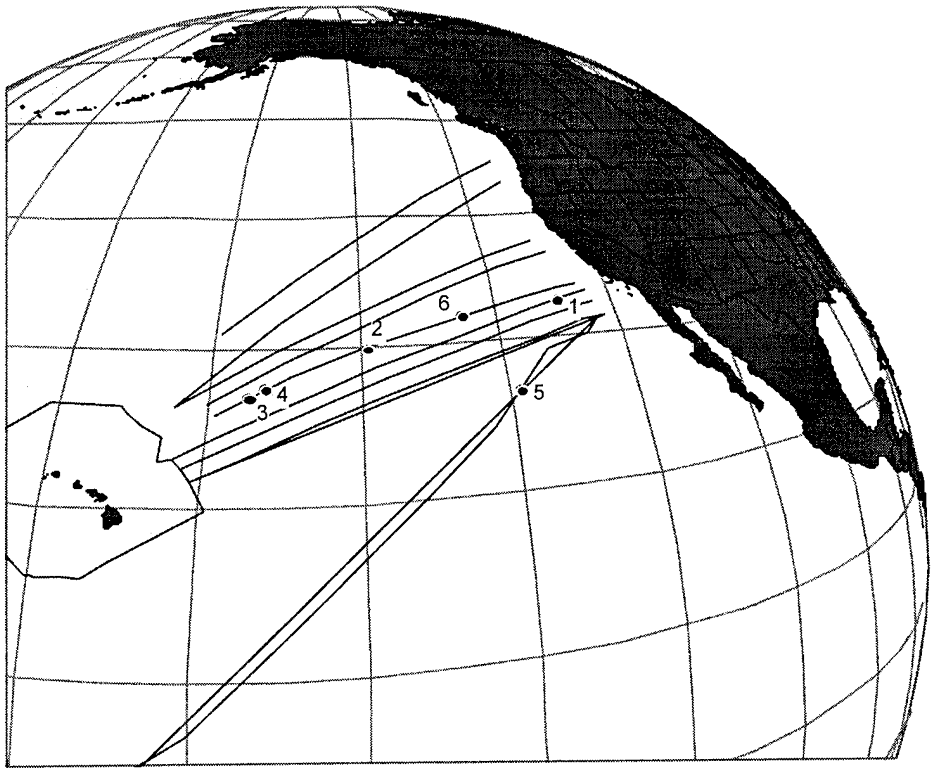

Illustration of locations of six ITC conditions.
Lines indicate the oceanic tracks on which the two aircraft were flying.

FIGURE 2. MAP OF PACIFIC OCEAN

2.3.5.1 Nominal Case.

The aircraft started 21 nautical miles (nmi) in-trail with a zero closure rate and with the lead aircraft at a 10° left offset on the climb aircraft's TCAS display. The lead aircraft was at flight level (FL) 350, and the climb aircraft was at FL330. The lead aircraft initiated a request (via simulated VHF) to climb. An ATC clearance was expected to be granted and the trailing aircraft began the climb at approximately 20 nmi separation. It was expected that the climb would proceed without incident and last approximately 6 minutes.

2.3.5.2 Interfering Traffic.

This condition illustrated interfering traffic at the target altitude. The climb aircraft performed a TCAS separation check on the lead aircraft and did not detect any traffic conflicting at the target altitude. However, there was traffic at the requested (target) altitude that was trailing the lead aircraft out of range of the TCAS. The controller checked for traffic at the target altitude and could deny the clearance.

2.3.5.3 Mis-Identified Lead Aircraft.

The pilot of the climb aircraft purposely mis-identified the lead aircraft in the initial ITC clearance request. This was done with the lead aircraft pilot's cooperation. This condition tested the controller's requirement to check the call sign of the lead aircraft to be sure the two aircraft were correctly identified and that contact had been made with the proper aircraft.

2.3.5.4 Closure Rate Too High Based on Assigned Mach Number.

This condition addressed the evaluation of the closure rate applicability criteria. The aircraft were initiated 18 nmi in-trail with a difference in filed Mach of 0.03 (approximately 20 knots [kt]). The lead aircraft was at FL340 and the climb aircraft was at FL320. This condition tested the controller's knowledge of the ITC procedure applicability rules.

2.3.5.5 Unable to Climb.

This condition addressed the possibility of a delay in communications that would cause the two aircraft to move too close to each other to allow an ITC. The initial request was made when the aircraft were approximately 18 nmi apart. A scripted communications delay of 8 minutes (min) and a closure rate of 30 kt caused the two aircraft to come within 15 nmi of each other. This tested the pilot's understanding of the specific criteria required for the ITC procedure.

2.3.5.6 Lead Aircraft Engine Out.

This condition addressed the possibility that the lead aircraft might lose power in one engine while the ITC maneuver was in progress. Just after the trailing aircraft began the climb, the lead aircraft lost power in one engine and power was subsequently lost to the TCAS transponder. This tested the pilot's understanding of the proper emergency procedures to be used during the ITC procedure.

2.3.6 Performance Measures.

The ITC procedure is defined by a series of actions and associated parameters. The performance measures for this experiment were based upon these actions and parameter value limits. The performance measures determined if the ITC procedure was followed properly and if the crews, controllers, and the simulation, in general, remained within the prescribed parameter values. The ITC procedure and the required parameter limits are summarized in appendix A.

The performance measures were divided into objective and subjective measures and are discussed separately in the following two subsections.

2.3.6.1 Objective Measures.

The purpose of the simulation experiment was to test the overall safety and practicality of the ITC procedure and the proposed training system. The objective measures assessed the effectiveness of the procedure and associated training techniques by gauging the performance of the pilots and controllers. The objective measures also assessed the safety of the procedure.

The objective measures were:

a. Observance of Applicability Rules. Were the applicability rules followed? The applicability rules defined in appendix A included specific procedures and parameters that could be objectively measured and compared. This measurement also assessed training effectiveness as well as the practicality of the rules and the procedure in general.

b. Correct Pilot Procedure. Did pilots execute the ITC procedure properly and use correct phraseology during communications? This also assessed the appropriateness and completeness of pilot training and cockpit checklists.

c. Correct Controller Procedure. Did controllers execute the ITC procedure properly and use correct phraseology during communications? This also tested the appropriateness and completeness of the controller training.

d. Operation within Procedural Limits. Did pilots and controllers execute the ITC procedure so that they satisfied all of the specified procedural limits? The key limits were:

1. Initial range between the aircraft (greater than 15 nmi, within TCAS range).
2. Minimum range between the aircraft (suggested no less than 10 nmi).
3. Initial rate of climb performance (500 feet per minute required).
4. Initial relative bearing angle at the start of the climb (less than 30 degrees left or right).

2.3.6.2 Subjective Measures.

The subjective judgments were made by the participating pilots, controllers, and observers. The data were collected by asking these participants to fill out forms in which they answered questions regarding each measure.

The subjective measures were:

a. Safety. Was the procedure safe? This was a rating of the procedure's safety based on pilot, controller, and observer questionnaire results and verbal comments. The ITC procedure was regarded as safe if a majority of the members in these groups rated it as such, and there were no major safety concerns.

b. Practicality. Is this procedure practical for implementation in today's cockpit and ATC environments? This was a rating of the ITC procedure's practicality in real world conditions based on pilot, controller, and observer responses. The ITC procedure was regarded as practical if a majority of the members of these groups rated it as such.

c. Workload. Would the additional workload, if any, rule against implementation of this procedure? Controller and pilot workload comparisons were made for the conditions with and without the ITC procedure. The ITC procedure was regarded as feasible if a majority of the participants stated that the additional workload (if any) was acceptable. Pilot workload was measured using the Modified Cooper-Harper (MCH) Questionnaire (Boff & Lincoln, 1988).

d. Simulation Realism. Was the simulation environment sufficiently realistic to allow the formulation of valid conclusions about the viability of the ITC procedure? Simulation realism was rated by controllers using a questionnaire. The ITC test bed was regarded as acceptable if a majority of the participants stated that the simulation environment was sufficiently realistic.

2.3.7 Data Collection.

Data collection consisted of three elements:

a. Video and audio recordings. Video recordings were made of the pilots and controllers during the simulation. Also, a video recording was made of cockpit screen displays for subsequent analysis.

b. Numerical data recordings. Numerical data were recorded at the climb aircraft and the lead aircraft workstations for later analysis. This included aircraft positions and other state information. Numerical data were also derived from the video and audio recordings.

c. Comment and questionnaire forms. Post-simulation comments and answers to questions were collected from pilots, controllers, observers, and evaluators. Copies of these forms are contained in appendix C.

2.4 ANALYSIS APPROACH.

2.4.1 Data Analysis.

Objective and subjective data were collected and analyzed to examine the various performance measures. Analysis of each condition determined the objective parameters of the simulation, including absolute aircraft separation distances. Subjective analysis included collecting and summarizing comments by simulation participants.

2.4.2 Analysis Procedures.

No complex statistical methods were applied for the ITC simulation experiment. The data analysis procedures consisted of formatting the numerical data, descriptive statistics, and plotting of the data for critical review by analysts. For the subjective data, the analysis procedures consisted of a review and summary of participant comments to determine the individual and group expert opinions.

3. ITC FULL MISSION SIMULATION PROCEDURES.

The following sections describe the procedures used for the ITC simulation.

3.1 STAFFING AND TRAINING REQUIREMENTS.

3.1.1 Staffing.

At the ODF, the simulation was staffed by operational air traffic controllers currently certified on oceanic sectors 3 and 4 of the Oakland ARTCC. The FAA HQ National Air Traffic Controllers Association (NATCA) provided one technical evaluator for the simulation. One ARINC

operator also participated. At the RCS, two separate airline crews, one each from UAL and DAL, staffed the climb aircraft simulator.

The FAA Technical Center provided technical support staff (human factors engineers, statistical analysts, and ODF/RCS technical support) to assist in the conduct of the simulation and analysis of the results. In addition, the FAA Technical Center Human Factors Laboratory (HFL) provided audio-video experts to instrument the ODF and RCS with audio and video recording equipment.

3.1.2 Training.

The following sections describe the training that was necessary for simulation participants.

3.1.2.1 Controller Participants.

Oakland ARTCC controllers were given 2 hours of ITC overview and practice using the FAA Technical Center's ODF to become familiar with the simulator. Although every attempt was made to duplicate the operational environment of the Oakland ARTCC oceanic work area, the FAA Technical Center's ODF differed slightly in performance and workspace configuration. Familiarization training included limited ITC simulation runs.

The controllers were trained and directed on the ITC procedure using the same training materials and procedures that are planned for operational use. This consisted of an ITC procedure briefing that is included in appendix C.

3.1.2.2 Pilot Participants.

Participating airline pilots were given 1 hour of overview and practice using the FAA Technical Center's RCS to become familiar with the simulator. Familiarization training included informal flight simulation runs. The pilots were also trained in the ITC procedure using the same training that will be given for operational use. Pilots were given approximately 1 hour to study the training materials before beginning the simulation. The material included an ITC procedure Pilot Training Bulletin that is included in appendix C.

3.1.2.3 Controller/Pilot Observers and Evaluators.

The controller and pilot observers and evaluators were given a tour of the facilities and an explanation of their role in the simulation. The experimenters explained the purpose of each simulation condition and what was expected during the simulation. The observers and evaluators were instructed to fill out forms (see appendix C) for data gathering purposes.

The controller observers were the FAA Air Traffic Procedures (ATP-140) representatives responsible for ITC oversight and a NATCA representative. The cockpit evaluators were the POIs for DAL and UAL, and the cockpit observers were representatives from FAA Flight Standards (AFS-430) responsible for overseeing development of the ITC procedure.

3.2 SIMULATION DESIGN PROCEDURES.

The following sections provide a description of the simulation procedures and subject scheduling.

3.2.1 General Procedures.

The ITC simulation was run over 2 days. One overall scenario (lasting 3 1/2 hours) was run each day. Within the scenario, six conditions were conducted, each of which represented an ITC situation.

The overall schedule of events for the simulation is given in table 2. Only the first day's schedule is shown; the second day was identical except for the use of the DAL crew in the RCS. Also, on the second day the order of the controller shifts was reversed.

3.2.2 Baseline Procedures.

For purposes of this simulation experiment, the baseline for the ITC was normal operations in the Oakland combined oceanic sectors 3 and 4. The controllers and pilots participating in the ITC simulation compared their daily work experience in the field with their experiences during the simulated ITC procedure in order to make workload evaluations and generate other comments.

3.2.3 ITC Experimental Conditions.

The experimental design for the ITC simulation experiment was the six conditions described in section 2.3.5. These represented a range of situations from nominal to extreme worst case.

3.3 CONFIGURATION MANAGEMENT.

Configuration management ensured repeatability for all simulation activities. All project materials were documented and retained in a library within the HFL building at the FAA Technical Center. These included documentation, questionnaire and observer forms, facility tapes, data reduction and analysis recording tapes and listings, and simulation run-time logs.

4. RESULTS: DATA COLLECTION SUMMARY.

This section summarizes the data collected during the 2 days of simulation for the ITC Full Mission Simulation Experiment. These data are analyzed in detail in appendix D.

4.1 VIDEO AND AUDIO RECORDINGS.

Video recordings were made of the pilots and controllers during the simulation. Also, a video recording was made of the pilots' cockpit screen displays. Review of these tapes resulted in a chronological list of all the critical events of the simulation and the numerical data discussed in section 4.3.

The video recordings, each lasting approximately 4 hours, included:

a. Pilots. Side view of climb aircraft pilots, including audio of all radio communications and discussions in the cockpit.

b. Cockpit Instruments. Direct recording of the video display in the climb aircraft cockpit, which included the TCAS and navigation displays.

c. Controller. Rear view of the controller's position, which included the controller, flight strips, and computer displays (not readable on the video recording).

TABLE 2. ITC NSC SIMULATION SCHEDULE

Day/Time	ODF	RCS
Thurs. 3/17/94		
08:30-09:00 Arrivals	Visitors arrive at main building, visitor's center. Split up into ODF and RCS groups and go to familiarization briefings.	
09:30	Introduction and ODF familiarization.	Introduction and RCS familiarization.
11:00	Controller training for ITC.	Pilot training for ITC (United Crew).
11:30	Lunch	Lunch
12:00	ODAPS access begins. Controllers/observers in positions.	
12:15	Initiate ODAPS.	
12:20	Synchronize ODAPS/ODF clocks.	
12:30	ODF communication system check.	Pilots/observers/evaluators and test crew in positions. Communication system check.
12:45		Initiate RCS. Synchronize ODAPS/RCS clocks.
12:45-16:30	First ITC condition. Controller A (First three conditions.)* (See detailed scripts.) Controller B (Second three conditions.) Final ITC condition complete.	
16:30	Break	
16:45	Debriefings (3rd Floor Conference Room)	Debriefings (HFL Conference Room)
17:30	First day complete.	

* On the second day, controller B began with the first three conditions, and controller A completed the remaining three.

4.2 PARTICIPANT QUESTIONNAIRES.

Data were collected from pilots, controllers, observers, evaluators, and other participants in the form of questionnaires. Copies of all forms are found in appendix C. The collected questionnaire data are summarized here:

a. Cockpit Observer Forms. One form for each of 6 conditions, for 1 day only (the cockpit observer decided not to use the form on the second day). [6 forms]

b. Cockpit Evaluator Forms. Two evaluators completed one form each for the two simulation days. [4 forms]

c. Flight Crew Debriefing. A total of four pilots completed this form. [4 forms]

d. Controller Quick Forms. Forms were filled out by controllers during the simulation. (Immediately following each condition, the controller filled out a portion of the form pertaining to the test just completed.) [2 forms]

e. Controller Debriefing Questionnaire. A total of four of these forms were completed by the two participating controllers, one for each day of the simulation. [4 forms]

f. Controller Observer Forms. These forms were completed on each of 2 days by two controller observers. [4 forms]

g. NATCA Comments. Printed comments from the NATCA Oakland ARTCC representative. [1 memo]

h. Debriefing Notes. A debriefing (discussion) session was held after each daily simulation run. These notes were taken during the debriefing and from audio recordings of the debriefings. [3 debriefing audio tapes and notes from 2 days]

4.3 NUMERICAL/QUANTITATIVE DATA.

Numerical data (aircraft position, speed, heading, etc.) would normally have been recorded directly by the RCS computer. This proved not to be possible due to limited software preparation time before the simulation was run. Instead, they were derived from the video and audio recordings by reviewing the videotapes and recording the data at regular intervals.

The numerical parameters derived from the videos for each of the 12 conditions (2 days, 6 conditions each) included:

a. Simulation time.

b. Altitude of climb aircraft (with the exception of Condition 6, the lead aircraft altitude was fixed).

c. Difference in altitude (lead altitude minus climb altitude).

d. Climb aircraft heading.

e. Climb aircraft ground speed.

f. Climb aircraft airspeed (Mach).

g. Climb aircraft rate of climb.

h. Range between the two aircraft.

i. Track offset distance and bearing angle.

Key portions of this data are plotted and analyzed in detail in section 5. Tabular listings of the numerical data can be found in appendix E.

5. RESULTS: DATA ANALYSIS SUMMARY.

Table 3 summarizes the data analysis and the results with respect to the experimental objective and subjective measures (section 2.3.6).

TABLE 3. DATA ANALYSIS SUMMARY

OBJECTIVE MEASURES	RESULTS	COMMENTS
Observance of Applicability Rules (Includes "Operation within Procedural Limits.")	Satisfactory[1]	1. The applicability rules were violated in one case. 2. Applicability rules (same track, range limits, relative bearing limits, the TCAS display and identification requirements, closure rate restrictions, and same or similar speed requirements) were all followed by pilots and controllers. (Verified by numerical quantitative data analysis and subjective observer responses.) One violation occurred. 3. The applicability rules appear to be sufficient. The quantitative data analysis showed that the two aircraft remained safely separated in all cases, even in the 'worst' (most improbable) case.
Correct Pilot Procedure	Satisfactory	1. Pilots, observers, and evaluators agreed that the procedure was adequate with minor modifications. 2. Observers and evaluators noted minor errors in the procedure, primarily in the order in which pilot performed steps or in phraseology used in communications. This resulted in several recommendations for minor training improvements, including a videotape explaining the procedure. 3. Several suggestions were made for items to be added to the cockpit checklist to ensure standard phraseology and proper order of the procedure execution.
Correct Controller Procedure	Satisfactory	1. Controllers, observers, and evaluators agreed that the procedure will be safe, practical, and will have little impact on workload with minor modifications. 2. Controllers made minor mistakes in procedure. In one case, a controller did not apply the normal oceanic separation standard requirement at the intended ITC altitude. Minor modifications to controller training were suggested. 3. Controllers were able to use ingenuity and standard techniques to grant ITC clearances when applicability rules did not initially allow it.

[1] As based on the analysis of objective and subjective data found in appendix D.

TABLE 3. DATA ANALYSIS SUMMARY (continued)

SUBJECTIVE MEASURES	RESULTS	COMMENTS
Safety	Satisfactory	1. All participants agreed that the procedure was safe. The general opinion was that, with minor modifications to the controller and pilot training and the pilot checklist, it could be safely implemented. 2. Cockpit evaluators recommended that ITC be allowed to progress to the flight trials phase. Cockpit observers stated the procedure was safe on the condition of recommended minor changes to training and checklists. 3. Controllers stated that they had high confidence in the procedure. Controller observers agreed, with minor modifications, they felt the procedure would be safe.
Practicality	Satisfactory	1. Pilots stated the procedure was easy to perform and that they could easily adapt to it and make use of it. 2. Controllers stated that the procedure would not be difficult with some minimal practice. The information provided to the controller was sufficient most of the time and the procedure is simply a variation on an existing procedure. 3. Observers and evaluators noted that the procedure seemed relatively simple. They noted the ability of controllers to adapt other standard procedures and integrate their use with ITC (such as slowing or climbing other aircraft to make an ITC possible).
Workload	Satisfactory	1. Pilots and controllers stated that the workload was not significantly affected by the addition of the procedure. The overall workload rating was average, without significant change from non-ITC conditions. 2. Controller observers noted that controllers became adept at working the ITC relatively quickly as they became used to it.
Simulation Validity and Realism	Satisfactory	1. Controllers expressed surprise at the level of realism in the ODF. They stated that it was very similar to Oakland ARTCC. 2. Pilots noted several minor differences between the RCS cockpit and realistic B747-400 cockpits, including some performance issues and control functions and capabilities. 3. Both pilots and controllers noted the realism of the communications, which used a qualified ARINC radio operator to relay messages.

6. CONCLUSIONS.

The In-Trail Climb (ITC) Full Mission Simulation Experiment was planned, developed, and executed successfully. This experiment tested the safety, practicality, and workload effects of using the ITC procedure in a simulated environment.

Experimental data were collected for six ITC conditions which spanned a wide range of situations. Data were gathered using questionnaires, video recordings, and numerical data logging. These data supported a set of objective and subjective measures, including:

Objective Measures

a. Observance of Applicability Rules.
b. Correct Pilot Procedure.

c. Correct Controller Procedure.
d. Operation within Procedural Limits.

Subjective Measures

a. Safety.
b. Practicality.
c. Workload.
d. Simulation Environment Realism.

Analysis of the experimental data indicated that the results were satisfactory for all measures. Both subjective and objective measures showed that the ITC procedure was safe, practical, and did not increase workload significantly for either pilots or controllers. Pilots and controllers were able to perform the procedure after standard training was completed. Minor difficulties and errors were experienced which led to recommendations for changes in the training manuals and the cockpit checklist. The fidelity of the simulation environment was considered excellent by the controllers and good by the pilots.

Overall, the results of the ITC Full Mission Simulation Experiment indicate the ITC procedure is safe and practical (with minor modifications of the training methods and pilot checklists) as evaluated in the simulated conditions described in this report. It is recommended that the planned flight trials of the ITC procedure be conducted as a final assessment prior to general implementation.

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Dillard, A. E. (April 1994). Oceanic in-trail climb using TCAS II - flight simulator validation tests final report. Washington, DC: FAA Office of Airspace Capacity and Requirements.

GLOSSARY

Climb Aircraft	The aircraft that performed the ITC.
Closure Rate	The rate at which the distance between the two aircraft decreased (in knots).
Full Mission Simulation	An integrated simulation in which all of the major systems and personnel are realistically represented.
In-Trail Climb (ITC)	Reference term for the maneuver of one aircraft climbing through the altitude of another in oceanic airspace along an oceanic track.
ITC Condition	A relatively short individual ITC situation in which one aircraft attempted to complete an ITC. Each condition lasted 20-30 minutes.
ITC Simulation Scenario	A single configuration containing a set of "conditions." Each condition included a set of flights with associated flight strips and a pre-defined schedule.
Lead Aircraft	The aircraft in the lead during the ITC.
National Simulation Capability	The FAA program to develop the infrastructure to integrate stand-alone ATC simulation elements into larger, integrated simulations.
Part-Task Simulation	A less integrated simulation in which portions of an entire system are simulated.
Simulation Evaluators	Technically knowledgeable persons who observe the simulation and evaluate the results.
Simulation Observers	Technically knowledgeable persons who observe the simulation and prepare comments and suggestions.
TCAS SAWG	TCAS Separation Assistance Working Group. A group of industry and government contributors working to develop methods whereby TCAS can be used to increase the efficiency of current airspace usage through the innovative use of existing and planned TCASs.

APPENDIX A
ITC PROCEDURE DEFINITION AND APPLICABILITY RULES

This appendix presents the applicability rules and the procedural requirements of the pilot and controller for the performance of the ITC procedure.

A.1 Applicability Rules.

The ITC applicability rules are as follows:

a. Same Track: The two aircraft must be on the same oceanic track.

b. Altitude Limit: The lead aircraft must be at the next available altitude level (e.g., 2000 ft). (The requested [destination] altitude is not restricted except by normal oceanic separation requirements.)

c. Range Limits: The lead aircraft must be within TCAS range (approximately 40 nmi) and outside of 15 nmi range of the trailing aircraft before the climb is initiated. Once the climb is initiated, the range can decrease below 15 nmi, but as a guide, should not decrease below 10 nmi.

d. Relative bearing limits: The lead aircraft must be within +/- 30 degrees relative bearing to the track of the trailing aircraft at the initiation of the climb.

e. Steady TCAS Display: The lead aircraft symbol displayed on the climb aircraft TCAS display must be steadily visible for at least 60 seconds before requesting the climb.

f. Closure Rate Restriction: The two aircraft must have a ground speed difference (closure rate) of less than 20 kt if within 20 nmi horizontal range, and less than 30 kt if greater than 20 nmi range as determined in the cockpit using TCAS.

g. Same or similar speed requirement. The two aircraft must be flying at the same or similar speed along the track. To the controller, this means the two aircraft must have a filed or assigned speed difference of less than or equal to .01 Mach or 20 kt.

A.2 Climb Aircraft Crew Procedure Requirements.

This section defines the required crew procedure for the ITC. The pilots must:

a. Establish the distance to the lead aircraft via electronic means (TCAS) and apply the steady TCAS applicability rule defined above.

b. Positively identify and verify the location and call sign of the lead aircraft through radio communications and by the TCAS on/off procedure. The lead aircraft crew is asked to briefly turn off their transponder and then turn it back on, which causes the lead aircraft TCAS symbol to disappear and reappear on the TCAS display.

c. Determine if they meet the closure rate restriction (see applicability rules).

d. Verify that the aircraft is capable of the climb to the requested altitude. They must also verify that the aircraft can meet the initial climb rate of 500 fpm.

e. Request the ITC using the proper phraseology and with all required information (including: own call sign, call sign of lead aircraft, range to lead aircraft, requested altitude, and reference to ITC).

A.3 Controller Procedure Requirements.

This section defines the required controller procedure for the ITC. The controller must:

a. Verify that the two aircraft are on the same track.

b. Verify that the lead aircraft has been correctly identified by the climb aircraft crew.

c. Verify that the climb aircraft is at the minimum vertical separation to start the procedure.

d. Verify that the two aircraft are at the same or similar speed (see applicability rules).

e. Verify that normal oceanic separation will be satisfied at the requested altitude and at all altitudes in between (except the altitude of the lead aircraft).

f. Apply the distance-based climb rule and issue a standard climb clearance.

g. Apply appropriate oceanic separation criterion at the new altitude.

APPENDIX B

SAMPLE ITC COMMUNICATIONS

This section presents an example of the communications scripts used as reference by the lead aircraft pseudo-pilots during the ITC.

Condition 1: Nominal Case

Initial Contact via VHF (at approximately 1:31)

Climb Aircraft Pilot:	"This is Delta 151, 120 miles east of DONER on R576. Aircraft 91 miles east of DONER at FL350 please identify yourself and state your altitude."
Lead Aircraft Pilot:	"This is Delta 161P 91 miles east of DONER on R576 at FL350."
Climb Aircraft Pilot:	"This is Delta 151. TCAS shows that we are 19 miles in-trail at FL330. We will be requesting a climb through your altitude to FL370."
Lead Aircraft Pilot:	"Roger."
Determine Closure Rate	
Climb Aircraft Pilot:	"Delta 161P, Delta 151 requests your ground speed."
Lead Aircraft Pilot:	"Delta 151, Delta 161P is going 488 knots."
Positive Identification	
Climb Aircraft Pilot:	"Delta 161P, for positive identification, please squawk standby."
Lead Aircraft Pilot:	"Roger, Delta 161P squawking standby."
	(pause 10 sec)
Climb Aircraft Pilot:	"Delta 161P, Delta 151 observes your transponder off, squawk normal."
Lead Aircraft Pilot:	"Roger, Delta 161P is squawking normal."
	(pause 10 sec)

Climb Aircraft Pilot:	"Delta 161P, Delta 151 observes your transponder is back on, we have a positive ID. We'll be requesting a climb through your altitude, currently 21 miles in-trail."
Lead Aircraft Pilot:	"Roger."

<u>Request Climb Clearance (HF)</u>

Climb Aircraft Pilot:	"San Francisco ARINC, Delta 151, over."
SFO ARINC:	"Delta 151, this is San Francisco ARINC, go ahead."
Climb Aircraft Pilot:	"San Francisco ARINC, Delta 151 is 21 miles in-trail of Delta 161P requesting climb to FL370 over."
SFO ARINC:	"Delta 151 San Francisco ARINC received your request for the in-trail climb 21 miles behind Delta 161P, standby."
Climb Aircraft Pilot:	"Roger, standing by."

(pause 3 min)

<u>Receive Clearance and Perform Climb</u>

SFO ARINC:	"Delta 151, this is San Francisco ARINC, over."
Climb Aircraft Pilot:	"San Francisco ARINC, Delta 151, go ahead."
SFO ARINC:	"Delta 151 ATC clears Delta 151 to climb and maintain FL370. Report reaching FL370."
	(check distance again, acknowledge ATC, then inform traffic and perform climb)
Climb Aircraft Pilot:	"Roger, Delta 151 leaving FL330 for FL370"
(Switch to VHF)	
Climb Aircraft Pilot:	"Delta 161P, Delta 151 leaving FL330 for FL370"
Lead Aircraft Pilot:	"Roger, Delta 161P leaving FL330 for FL370."
	(start climb... watch airspeed)

<u>Notify When Climb is Complete (HF then VHF)</u>

Climb Aircraft Pilot:	"San Francisco ARINC, Delta 151, over."
SFO ARINC:	"Delta 151, this is San Francisco ARINC, go ahead."
Climb Aircraft Pilot:	"San Francisco ARINC, Delta 151 maintaining FL370."

SFO ARINC:	"Roger, level at FL370."
	(switch to VHF)
Climb Aircraft Pilot:	"Delta 161P, Delta 151 maintaining FL370."
Lead Aircraft Pilot:	"Roger, Delta 151."

APPENDIX C

TRAINING AND DEBRIEFING FORMS

This appendix presents the training materials and participant questionnaires and debriefing forms used in the ITC Full Mission Simulation Experiment.

C.1 CONTROLLER TRAINING.

This section contains a draft copy of the supervisor controller's briefing that will be used to train supervisors in the ITC procedure. This version is not final and is included here only for illustrative purposes. This material was used for the purpose of the ITC simulation, and may change before being published.

Draft Supervisor Briefing [Controller Supervisor]

Background

The ITC procedure was derived from the current non-radar separation rule utilizing longitudinal separation minimum based on distance as outlined in the FAA Order 7110.65 and the ICAO Rules of the Air and Air Traffic Services (Doc. 4444). The intent of the procedure is to utilize the Traffic Alert and Collision Avoidance System (TCAS) as a distance measuring device and apply non-radar distance measuring equipment control procedures. This procedure authorizes a modified "up in back rule." Once the pilot determines the distance in-trail and requests the climb, the TCAS is no longer required.

The following change will be incorporated into FAA Order 7110.65 for use in oceanic regions:

Procedure

When a climb request is received with distance from traffic information included, the controller will know that the procedure is authorized and that the TCAS distance-based rule is applicable.

Aircraft climb: When an aircraft is climbing through the altitude of another aircraft on the same track, separation can be reduced to 15 nmi provided:

a. The distance between aircraft is established through electronic means (TCAS).

b. The climb aircraft is following and at the minimum vertical separation from the traffic.

c. The aircraft have filed the same or similar speed. Mach speed assignment is NOT a requirement.

d. The appropriate oceanic separation criterion exists at the new altitude.

Duties

The controller will:

a. Determine if the traffic referenced in the request is the correct traffic for the climb.

b. Assure the maneuvering aircraft is along the same track and at the minimum vertical separation to start the procedure.

c. Assure the aircraft are at similar speeds (within 20 kt or .01 Mach).

d. Apply the distance-based climb rule and issue a standard climb clearance.

e. Apply appropriate oceanic separation criterion at the new altitude.

The pilot will:

a. Positively identify the traffic ahead and determine the distance between the aircraft is at least 15 nmi using the TCAS traffic display.

b. Determine the aircraft can achieve an initial climb of at least 500 feet per minute.

c. Include the call sign of the traffic ahead in the request for the in-trail climb.

d. NOT execute the maneuver if the distance reduces to less than 15 nmi, when the clearance is received, due to delays in communications.

Example

When ATC receives a clearance request identifying traffic by a call sign and distance, the requesting aircraft certifies that: 1) the traffic has been positively identified, 2) the distance to the traffic has been determined using the TCAS display, and 3) the pilots are in communication with each other. This is the controller's authorization to apply the ITC procedure.

The pilot will forward the request through ARINC and it will appear in the following text:

"UAL125 is 23 nmi in-trail of DAL30, requesting FL370."

If all the conditions for the procedure are met and a clearance can be issued, the controller will issue a standard climb clearance.

"ATC clears UAL125 climb to and maintain FL370, report reaching."

The distance reported in the request will be recorded in the flight progress strip to differentiate the application of the ITC procedure. This can be in field 26 or by local application.

The responses received from UAL125 after receiving the climb would be the same as with any climb today.

"UAL125 is out of FL330 for FL370."

"UAL125 at FL370."

Summary

The distance-based ITC procedure was effective on March 10, 1994. All crews shall be briefed on the new application. Supervisors will ensure all controllers understand the applicability of the new procedure and then record an entry in the employee's training records.

C.2 Controller Debriefing Questionnaire.

Figure C-1 contains the controller's debriefing form provided to the controllers after the ITC simulation was completed.

CONTROLLER DEBRIEFING QUESTIONNAIRE
ITC Full-Mission Simulation

Please fill out this brief questionnaire.

---

1. Was the information you received from the pilot complete?

(yes) (no)

---

2. Was the pilot information you received in the format you expected?

(yes) (no)

---

3. Was the strip marking for the ITC procedure sufficient?

(yes) (no)

If not, how would you make it better?

---

4. Rate the overall effectiveness of the ITC procedure.

1	2	3	4	5
Very Low		Medium		Very High

---

5. Rate your overall workload during this run using the Modified Cooper-Harper rating scale (see handout).

1 2 3 4 5 6 7 8 9 10

---

6. How do you feel the ITC procedure will effect the controller's workload?

---

7. If you were a relieving controller, was it apparent that an ITC maneuver had taken place?

(yes) (no)

FIGURE C-1. CONTROLLER DEBRIEFING QUESTIONNAIRE FORM

C.3 Controller Quick Form Questionnaire.

Figure C-2 contains the controller's quick-form questionnaire that was provided to the controllers before the ITC simulation was begun. This form was filled in after each condition was completed.

CONTROLLER QUICK FORM QUESTIONNAIRE
ITC Full-Mission Simulation

Date ________

1. CONTROLLER SCENARIO QUESTIONNAIRE.

You will be asked to verbally give a rating for the following questions at the completion of each scenario during the simulation.

1. Was the pilot information received adequate?

   (yes) (no)

2. Give a workload rating for the mini-scenario just completed. Base your answers on the scale given below.

1	2	3	4	5
Very Low		Medium		Very High

FIGURE C-2. CONTROLLER QUICK FORM QUESTIONNAIRE (Page 1 of 2)

Date ______________

1. ENOUGH INFORMATION? [YES-NO]

SCENARIO #	YES/NO
1	
2	
3	
4	
5	
6	

2. GIVE WORKLOAD RATING [1-5]

SCENARIO #	RATING
1	
2	
3	
4	
5	
6	

FIGURE C-2 CONTROLLER QUICK FORM QUESTIONNAIRE (Page 2 of 2)

C.4 Controller Observer Form.

Figure C-3 contains the controller observer's form provided to the observers after the ITC simulation was begun.

Date _______________

OBSERVER FORM
ITC Full-Mission Simulation

Please fill out this brief questionnaire on the mini-scenario as it is completed.

1. Was the controller given adequate information to perform ITC procedure?

#	1	2	3	4	5	6
Yes/No						

2. What was the reported distance to the lead aircraft?

#	1	2	3	4	5	6
nmi						

3. Was the climb: A-Approved or D-Disapproved?

#	A/D	CLEARANCE	RESPONSE TO REQUEST
1			
2			
3			
4			
5			
6			

FIGURE C-3. CONTROLLER OBSERVER FORM (Page 1 of 3)

4. Did the controller follow the procedure as outlined?

#	1	2	3	4	5	6
Yes/No						

5. Give a workload rating for the controller:

1	2	3	4	5
Very Low		Moderate		Very High

#	RATING	COMMENTS
1		
2		
3		
4		
5		
6		

6. Please make any additional comments here.

FIGURE C-3. CONTROLLER OBSERVER FORM (Page 2 of 3)

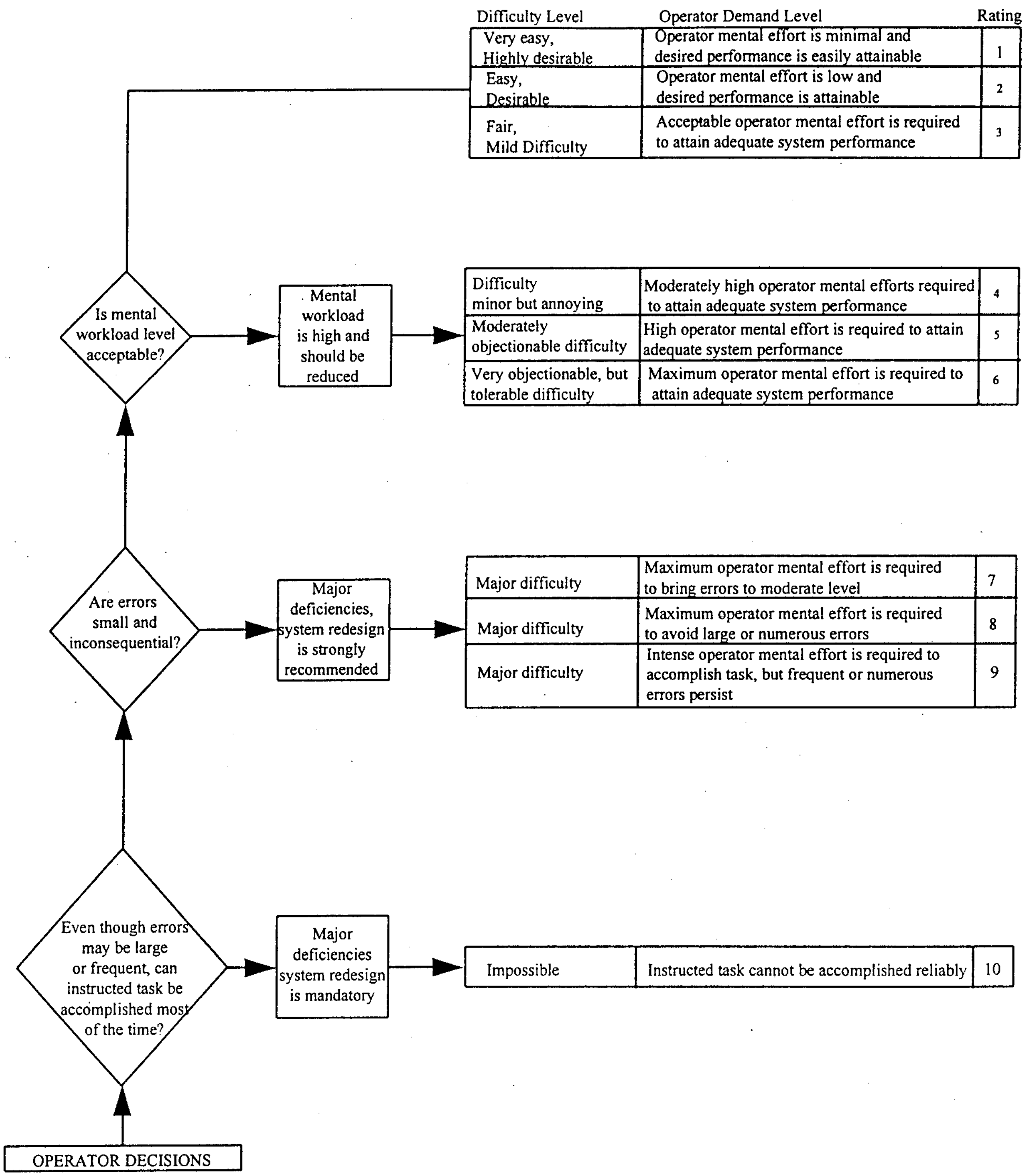

FIGURE C-3. CONTROLLER OBSERVER FORM
(MODIFIED COOPER-HARPER RATING INSTRUCTIONS)
(Page 3 of 3)

C.5 Pilot Training Bulletin.

Figure C-4 contains the Pilot Training Bulletin to be provided to the pilots before the start of the ITC simulation experiments.

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File This Temporary Revision Facing
Page 77 NAVIGATION Section

TCAS IN-TRAIL CLIMB (ITC)

- This procedure is intended to be used in non-radar environments to enable a trailing aircraft to climb to a higher flight level.
- The autopilot must be used for the climb.
- Both pilots must remain in their seats during the entire maneuver.
- TCAS Resolution Advisory (RA) policies remain in effect.
- ITC procedure is not authorized if displayed target is intermittent.
- Radar display of TCAS must be used for the maneuvers.

In-Trail Climb Preparation:

DETERMINE MAXIMUM ALTITUDE WITH FMC
- Climb above maximum altitude prohibited.

CHECK FLIGHT LEVEL AVAILABILITY
- Select TCAS above mode.

ESTABLISH VHF COMMUNICATIONS WITH LEAD AIRCRAFT
- On oceanic common, confirm lead aircraft is a Delta or United aircraft to coordinate TCAS ITC.

PERFORM TCAS POSITION
- Both pilots observe target drop/return when lead aircraft squawks standby/normal.

In-Trail Climb Procedure Initial Requirements:

TARGET BEARING.....WITHIN 45 DEGREES OF NOSE

MINIMUM RANGE TO START
- Range separation more than 20 nm: 30 knots.
- Range separation 20 nm or less: 20 knots.

REQUEST ATC IN-TRAIL CLIMB CLEARANCE
- Identify traffic by call sign and separation distance.
- Radio, Delta ___ is ____ miles in trail of Delta ___, request climb FL____.

FIGURE C-4. PILOT TRAINING BULLETIN (Page 1 of 2)

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When In-Trail Climb Clearance Received:

ADVISE LEAD AIRCRAFT
- Advise lead aircraft of climb clearance.
- Request lead aircraft notify of any change in speed, altitude, or heading.

INITIATE CLIMB TO ASSIGNED FLIGHT LEVEL
- Advise ATC departing FLxxx for FLxxx.
- Once climb initiated, advise ATC if unable to sustain 500 fpm rate of climb.
- Range to traffic may decrease to less than 15 nm once climbing.

If Unable to Comply with ATC Clearance, or if Initial Requirements are No Longer Valid When Clearance Received:

ADVISE ATC OF
- "Unable climb, descending/maintaining Fl___."
- ATC is clearing both the new and old altitudes until a report is made to confirm established altitude.

ADVISE LEAD AIRCRAFT

When Established at New Flight Level:

ADVISE ATC
- Standard oceanic spacing criteria is once again applied

ADVISE LEAD AIRCRAFT

--------END OF PROCEDURE-----

FIGURE C-4. PILOT TRAINING BULLETIN (Page 2 of 2)

C.6 Pilot Debriefing Form.

Figure C-5 contains the pilot's 2-page debriefing form provided to the pilots after the ITC simulation was completed.

FLIGHT CREW DEBRIEF FORM
ITC Full-Mission Simulation

This form should be used by pilots to provide feedback on the ITC procedure and the adequacy of training materials. The first section is for your comments on the task categories as listed in the order that they occurred. The second section has a few questions regarding adequacy of the training materials, checklists, and the use of the traffic display to determine range. Your judgment of the overall safety of the procedure is also requested.

Name (Optional): ______________________ **Airline:** ______________________

Estimated total flight time: ______________ **Oceanic experience (years):** ____________

Crew Position (circle one): **Captain** **First Officer** **Intl. Relief Pilot**

INSTRUCTIONS: For each element of the ITC procedure outlined below, please comment as desired.

TASKS	COMMENTS
Before Establishing Communications With Lead Lead aircraft distance at least 15 nmi. Target bearing 45° or less. Lead aircraft at next flight level. No other displayed targets within + 2000' of lead. Climb capability checked (flt. level and rate). Crew coordination.	
Communications with Lead Determine flight number and call sign. Determine position and altitude. Determine ground speed. Communicate intent to climb.	
Closure Rate Check Ground speed closure is appropriate for distance.	
Identification Proper use of Standby/Normal ident procedure.	
ATC Clearance Request includes lead distance and call sign.	
After ATC Clearance Received Prior to climb, verify distance. Inform lead that clearance has been received. Request lead provide pertinent information.	
During Climb Perform climb on autopilot/autoflight system. Initial climb performance at least 500 fpm.	
Established at New Flight Level Report level to ARINC. Report level to lead.	
Contingencies Emergencies/contingencies use standard proc.	

FIGURE C-5. PILOT DEBRIEFING FORM (1 of 2)

FLIGHT CREW DEBRIEF FORM
ITC Full-Mission Simulation

INSTRUCTIONS: For each question below circle your response and comment, as desired.

What is your level of confidence in the safety of this procedure? Low Med High

Comments:

Did the training materials adequately prepare you to accomplish the procedure? Yes No

Comments:

Did the cockpit reference checklist provide enough information to safely accomplish the procedure? Yes No

Comments:

Was it easy to determine range to the lead aircraft using the traffic display? Yes No

Comments:

Do you have any suggestions for improvement of this procedure?

FIGURE C-5. PILOT DEBRIEFING FORM (2 of 2)

C.7 Pilot Evaluator Form.

Figure C-6 contains the pilot evaluator's debriefing form provided to the evaluators after the was completed.

COCKPIT EVALUATOR FORM

ITC Full-Mission Simulation

This form is provided as an evaluation template for the ITC Full-Mission Simulation. The tasks are presented in the order in which they will occur during the conduct of each simulation scenario. Each task category should be marked (S) when pilot performance is judged satisfactory. If performance is unsatisfactory, mark the category (U), and provide explanation in the space provided. If task is not applicable, leave blank. Please use the back of the form for additional comments.

TASKS	SCENARIO 1	2	3	4	5	6
Before Establishing Communications With Lead Lead aircraft distance at least 15 nmi. Target bearing 45° or less. Lead aircraft at next flight level. No other displayed targets within + 2000' of lead. Climb capability checked (flt. level and rate). Crew coordination.						
Communications with Lead Determine flight number and call sign. Determine position and altitude. Determine ground speed. Communicate intent to climb.						
Closure Rate Check Ground speed closure is appropriate for distance.						
Identification Proper use of Standby/Normal identification procedure.						
ATC Clearance Request includes lead distance and call sign.						
After ATC Clearance Received Prior to climb, verify distance. Inform lead that clearance has been received. Request lead provide pertinent information.						
During Climb Perform climb on autopilot/autoflight system. Initial climb performance at least 500 fpm.						
Established at New Flight Level Report level to ARINC. Report level to lead.						
Contingencies Emergencies/contingencies use standard proc.						

Comments (If necessary, continue on reverse):

Name: ________________________ **Signature:** ________________________ **Date:** ___________

FIGURE C-6. COCKPIT EVALUATOR FORM

C.8 Cockpit Observer Form.

Figure C-7 contains the cockpit observer's debriefing form provided to the observers before the ITC simulation began.

COCKPIT OBSERVER FORM
ITC Full-Mission Simulation

This form should be used to comment on the ITC flight crew procedures and effectiveness of training methods. Tasks are presented in the order in which they will occur during each simulation scenario. Record your comments in the space provided. If you need additional space, use the back of this form.

Name: ______________________ **Affiliation:** ______________________ **Date:** __________

Scenario Number (circle 1) 1 2 3 4 5 6

INSTRUCTIONS: For each element of the ITC procedure outlined below, please comment as desired.

TASKS	COMMENTS
Before Establishing Communications With Lead Lead aircraft distance at least 15 nmi. Target bearing 45° or less. Lead aircraft at next flight level. No other displayed targets within + 2000' of lead. Climb capability checked (flt. level and rate). Crew coordination.	
Communications with Lead Determine flight number and call sign. Determine position and altitude. Determine ground speed. Communicate intent to climb.	
Closure Rate Check Ground speed closure is appropriate for distance.	
Identification Proper use of Standby/Normal ident procedure.	
ATC Clearance Request includes lead distance and call sign.	
After ATC Clearance Received Prior to climb, verify distance. Inform lead that clearance has been received. Request lead provide pertinent information.	
During Climb Perform climb on autopilot/autoflight system. Initial climb performance at least 500 fpm.	
Established at New Flight Level Report level to ARINC. Report level to lead.	
Contingencies Emergencies/contingencies use standard proc.	

What is your level of confidence in the safety of this procedure? Low Med High

Comments (If necessary, continue on reverse):

C-7. COCKPIT OBSERVER FORM

APPENDIX D

DATA ANALYSES AND DISCUSSIONS

This section presents the detailed collection and analysis performed on the data described in section 4. The following subsections discuss the cockpit results, the ODF or ATC results, the results of the debriefings, and finally the quantitative analysis of the numerical data.

D.1 Cockpit Data Analysis.

D.1.1 Pilots.

D.1.1.1 Pilot Responses to Questionnaires.

Each of the four pilots was asked to fill out a Flight Crew Debriefing Questionnaire (see appendix C). This questionnaire consisted of two pages. The first page asked for basic background information on the pilot and comments on each step of the procedure. On the second page, pilots were asked a series of questions regarding their opinion of the ITC procedure. Each question had an answer to select and room for comments. Table D-1 summarizes the pilot responses to both pages of the debriefing questionnaire.

TABLE D-1. PILOT DEBRIEFING RESPONSES

Procedure Step/Task	S/U*	Pilot Comments
Before Establishing Communications with Lead	S: 4 U: 0	"Put key parameters in checklist." "Exact parameters would be helpful."
Communications with Lead	S: 4 U: 0	"Good procedure."
Closure Rate Check	S: 4 U: 0	"It would be good to have the numbers [on the checklist]."
Identification	S: 4 U: 0	
ATC Clearance	S: 4 U: 0	
After ATC Clearance Received	S: 4 U: 0	"Put this [that lead should provide pertinent information] in the checklist."
During Climb	S: 4 U: 0	
Established at New Flight Level	S: 4 U: 0	
Contingencies	S: 2 U: 2	"Not spelled out adequately in bulletin. Need more precise/better examples." " 'Unable Climb' standard of what to do should be on the card [checklist]."

* Satisfactory or Unsatisfactory. Number of pilots indicating this step was clear and satisfactory or not satisfactory. Total number of pilots in the sample was 4.

TABLE D-1. PILOT DEBRIEFING RESPONSES

Questions	Response	Pilot Comments
What is your confidence in the safety of this procedure? (High, Med., Low)	"High" 4 of 4	"A good procedure, but will not get much use if only United-United, or Delta-Delta. Should include *all* oceanic-TCAS users." "Should be no problem when the 'start' parameters are met." "This is a very safe and efficient procedure... need to communicate to the other pilots."
Did the training materials adequately prepare you to accomplish the procedure?	"Yes" 4 of 4	"Videotape with possible contingencies and appropriate (book answer) procedures." "Need a video and/or some prior academics [classroom training] to get the big picture."
Did the cockpit reference checklist provide enough information to safely accomplish the procedure?	"Yes" 3 of 4	"It would be good to have the numbers [on the checklist]." "Yes if there were no complications. With Murphy's Law it was inadequate."
Was it easy to determine the range to the lead aircraft using the traffic display?	"Yes" 4 of 4	"No problem."
Do you have any suggestions for improvement of this procedure?		"Publish cockpit checklist for procedure." "Put 'asking for his ground speed' up with 'communications - establish'." "When starting your climb, inform him of the need to have his ground speed, altitude and heading changes when you tell him you're leaving X FL for next FL." "Incorporate verbiage and practical minimums/guidelines into checklist, such as: a. minimum range after initiation, b. maximum closure rate after initiation, c. loss of display, d. loss of communications, e. greater than 30 degree bearing after initiation, f. lead aircraft descends for engine loss/rapid decompression, g. minimum distance for aircraft behind climb aircraft if able to show on TCAS, h. maximum range scale to use if limiting climb to only one aircraft on the display." "Overall an excellent procedure. With slightly more detailed checklist and *most* contingencies explained with proper/expected solutions, it will work well."

D.1.1.2 Summary of Pilot Data.

The following summarizes the pilots' responses:

a. The overall procedure was considered safe and practical, and the pilots expressed strong confidence it will work. They had no concern about additional workload, indicating the procedure was considered feasible from the pilots' point of view.

b. Improved checklist: The pilots suggested the inclusion of several additions to the checklist.

c. Improved training: Two pilots suggested the inclusion of a videotape into the training (in addition to the Pilot Training Bulletin). Also, several suggestions were made for additional information on the Bulletin itself, similar to the data and additional information suggested for the checklist.

D.1.2 Cockpit Evaluators.

D.1.2.1 Cockpit Evaluator Data Analysis.

The cockpit evaluators were asked to fill out a Cockpit Evaluator Form as they observed the crew performing the ITC procedure. (This form is included in appendix C.) Two evaluators filled out the form once for each of the two simulation days. Table D-2 summarizes the evaluator's responses and comments on each procedure step.

In addition to the questionnaire responses, the cockpit evaluators provided several comments. These are summarized here for each evaluator, sorted by day. Some of the comments were unsatisfactory, but none were safety-critical.

Day 1: Evaluator #1.

a. "Need to make sure checklist has enough information on it which covers necessary items and is easy and straightforward to use. Crew suggested sample radio call."

b. "Based on crew comments and observations, recommend that a training video be required prior to allowing line crews to implement procedure."

c. "Recommend checklist contain confirmation of climb capability (performance)."

d. "Crew was able to accomplish procedure safely in all conditions based on information available to them. There was some uncertainty about longitudinal separation requirements with an aircraft behind them. Also, some question about minimum separation during the climb. These two areas should be addressed in the training materials."

e. "I feel that this procedure should be allowed to progress to the actual aircraft trial stage."

TABLE D-2. COCKPIT EVALUATOR RESPONSES

Procedure Step/Task	S/U*	Cockpit Evaluator Comments
Before Establishing Communications with Lead	S: 24 U: 0	
Communications with Lead	S: 24 U: 0	"Generally made separate radio call to determine ground speed or lead aircraft. Should request when informing of intent to climb."
Closure Rate Check	S: 24 U: 0	
Identification	S: 24 U: 0	"Requested clearance prior to positive ID."
ATC Clearance	S: 22 U: 2	"Some confusion on clearance request." "Should use precise verbiage that ATC understands."
After ATC Clearance Received	S: 14 U: 10	"Forgot to ask lead aircraft to advise of change in ground speed during climb on two occasions and was late on two other occasions." "During Condition 1, 2, 4, 5 and 6, flight crew failed to request that lead aircraft notify them of any change in speed, altitude, or heading."
During Climb	S: 24 U: 0	
Established at New Flight Level	S: 24 U: 0	
Contingencies	S: 24 U: 0	
Totals:	S: 204 U: 12	(94% Satisfactory)

* S/U - Satisfactory/Unsatisfactory. Number of simulation conditions completed satisfactorily (2 evaluators X 6 conditions X two days = 24 total).

Day 1: Evaluator #2.

a. "Crew decreased Mach in climb from .86 to .83 [Mach] during Condition 1 without advising ATC."

b. "Once clearance was requested, the crew saw the conflict traffic (on TCAS) behind and above at target altitude and canceled clearance request. (Better to let ATC perform their job and either approve or deny request.)"

c. "Flight crew realized that closure rate was too great and requested a lower Mach in order to maintain separation and improve chances for approval of climb clearance."

d. "Flight officer wanted to descend aircraft when contact was lost with lead on VHF and TCAS. Captain quickly determined that climb should be continued per guidance."

e. "A safe procedure but a video to supplement Training [Pilot Training] Bulletin could greatly increase the transfer of information to the flight crew. Possibly a video should be considered once the trial period is ended. This video could be entered into recurrent/in-trail training if required by FAA. Computer Based Instruction and Training (CBIT) would be an acceptable training supplement."

Day 2: Evaluator #1.

a. "Checklist accomplished out of sequence cause some confusion at times. Emphasis should be put on doing checklist in normal sequence."

b. "Recommend that precise verbiage when talking with ATC be emphasized to avoid confusion."

c. "Procedure was conducted safely and recommend progress to the aircraft trials."

Day 2: Evaluator #2.

a. "No positive ID of aircraft prior to ATC request. Positive [ID] was completed prior to climb."

b. "Too much information provided to ATC."

c. "A statement concerning what ATC expects might aid in cutting down on the information exchange."

d. "Overall, crew failed to use all aspects of list provided to them."

e. "Procedure continues to be safe even with the crews not following all procedures."

D.1.2.2 Summary of Cockpit Evaluator Data.

The following is a summary of the cockpit evaluator responses:

a. The overall procedure was considered generally safe. Even with some problems with communications and checklists, the procedure was conducted safely in all cases. If these issues can be remedied, the procedure would be considered safe.

b. Several recommendations were made that fall into the following categories:

1. Communications irregularities: Pilots failed to perform communications in the proper order, used imprecise verbiage, or conveyed too little or too much information to ATC.

2. Checklist inadequacy: Evaluators noted several instances where a more complete and/or detailed checklist, with more examples or specific parameters, or precise radio communications verbiage, would have helped the pilots in conducting the procedure more smoothly.

3. Training inadequacy: Both evaluators recommended that a training video be added to the Pilot Training Bulletin as a regular part of the ITC procedure training.

c. Both cockpit evaluators recommended that the procedure be allowed to progress to the flight trials stage.

D.1.3 Cockpit Observer.

D.1.3.1 Cockpit Observer Data Analysis.

The cockpit observer was asked to fill out a form while observing the crew performing the ITC procedure. This form is included in appendix C (Cockpit Observer Form). Table D-3 summarizes the observer's responses and comments on each procedure step. Each individual condition was evaluated for a total of 6 responses.

TABLE D-3. COCKPIT OBSERVER RESPONSES

Procedure Step/Task	S/U*	Cockpit Observer Comments
Before Establishing Communications with Lead	S:6 U:0	Condition #3: "Good instruction." Condition #4: "Good, but too much indecision on how much to improvise."
Communications with Lead	S:6 U:0	Condition #4. "Made speed adjustment request."
Closure Rate Check	S:5 U:1	Condition #4. "No, but requested Mach adjustment."
Identification	S:6 U:0	
ATC Clearance	S:6 U:0	
After ATC Clearance Received	S:6 U:0	
During Climb	S:6 U:0	Condition #1 "Had to reduce to 300 fpm after FL350, did inform ARINC radio of performance change."
Established at New Flight Level	S:5 U:1	Condition #6 "No, but offered assistance (after lead aircraft engine out)."
Contingencies	S:6 U:0	Condition #2 "Recognized aircraft behind." Condition #6 "Recognized aircraft could continue to new altitude."
What is your level of confidence in the safety of this procedure? (Low, Med., or High)	High:0 Med: 5 Low: 0	1 condition: No answer.
Totals:	52 / 2	(96% Satisfactory, excluding safety rating.)

* S/U: Satisfactory/Unsatisfactory. Total of 6 responses. (Not completed for day 2.)

The cockpit observer provided several comments and recommendations in addition to the questionnaires. These are summarized here.

Day 1: Condition #1.

"Although first run, a lot of dedicated attention was utilized for profile."

Day 1: Condition #2.

a. "The TCAS was used as a CDTI [Cockpit Display of Traffic Information] which enhanced the cockpit crew's situation awareness of traffic in front and behind. This usage of TCAS is a good check and balance with the controller for separation above, below, and behind. This could be added to the procedure for enhanced situation awareness and interaction with ATC."

b. "There seems to be some indecision as to the parameter of the climb guidelines (i.e., 15 nmi/bearing angle)."

Day 1: Condition #3.

"Once normal climb procedure (ITC) was altered due to traffic problem, the adaptive inquiry needs to be expanded for situation awareness pattern. Display interpolation needs better pattern recognition."

Day 1: Condition #4.

"How much improvising will be allowed to normal procedure will be incorporated [into Operations Bulletin]."

Day 1: Condition #5.

"Crew recognized separation distance (less than 15 nmi)."

Day 1: Condition #6.

"Crew used inquiry to reestablish contact and offered assistance."

D.1.3.2 Observer Recommendations.

a. "Five minute videotape that shows narrated procedure with Operations Bulletin. Pilots process over 75% of information visually, especially when busy. Could be used like airport qualification tapes at each crew base."

b. "If procedure has not [been] utilized within 90 days, crew should review video again before using procedure."

c. "Video should be shown during recurrent as a closed-loop feedback to fine-tune procedure."

d. "If training transfer is not adequate second level instruction should be considered."

e. "Ideal area for reinforcement and creative improvising would be no threat to Line Oriented Flight Training (LOFT) simulations."

f. "Hard copy (i.e., check list card) of ITC should be kept with other checklists (normal, emergency, ITC)."

g. "Protocol needs fine tuning as to how much improvising can be initiated before emergency authority implemented."

D.1.3.3 Cockpit Observer Summary.

The following summarizes the cockpit observer's results:

a. The overall procedure was evaluated as medium for safety, and several changes to the training and checklist were recommended. The observer's overall score (52/54 = 96%) was about equal to the cockpit evaluators' (204/216 = 94%).

b. Several recommendations were made in the following categories:

1. Training: The cockpit observer also suggested use of video training and the LOFT simulation training system. Currency should be maintained with 90-day reviews. Second-level instruction should be considered.

2. Checklist: Add the ITC checklist to those carried by pilots.

c. The observer comments indicated that the procedure is expected to be safe, practical, and feasible if the suggested changes are implemented.

D.2 Controller Data Analysis.

The ITC Full Mission Simulation was unique in that it used a high fidelity emulation of the controller's position, in addition to the cockpit simulator. This section discusses the ITC procedure from the point of view of the ATC participants. These included the controllers and the controller observers. Data were collected to measure the safety, workload, and feasibility of the procedure with controllers in a realistic environment.

D.2.1 Controllers.

The controllers provided information on the simulation results with two forms: the Controller Quick Form, and the Controller Debriefing Questionnaire. Both of these forms are included in appendix C. The results of the first form are summarized in table D-4.

TABLE D-4. CONTROLLER QUICK FORM RESPONSES

Question	Condition	Yes	No
Are you receiving enough information?	1	2	0
	2	2	0
	3	2	0
	4	2	0
	5	2	0
	6	2	0
		Ratings*	
	Condition	#1**	#2
Give workload rating.	1	3	2
	2	2-3	4
	3	2	4
	4	3	3
	5	2	3
	6	3	2
Averages		2.6	3.0

* Ratings from 1-5, 5 being higher workload.
** #1/#2 refers to controllers #1 and #2.

This table of results indicates that the controllers received enough information to conduct the procedure, and that the workload was average (no change from their current workload).

Table D-5 summarizes the Controller Debriefing Questionnaire, which was filled out each day by controllers after the simulation and the debriefing were completed. A total of four forms were collected from two controllers.

TABLE D-5. CONTROLLER DEBRIEFING QUESTIONNAIRE RESULTS

Question	Yes*	No*	Comments
1. Was the information you received from the pilot complete?	2	2	"At one point, DAL25 requested ITC without giving mileage."
2. Was the pilot information received in the format you expected?	2	2	"Ran on ODAPS 1.2 instead of 1.0."
3. Was the strip marking for the ITC procedure sufficient?	4	0	
4. Rate the overall effectiveness of the ITC procedure (one form for each controller for each day). Average	Form 1 2 3 4	R4** 5 4 3 4 4	"I don't know how much it would be used or available for use."
5. Rate your overall workload during this run using the MCH rating scale (one form for each controller for each day). Average	Form 1 2 3 4	R5*** 2 4 4 5 3.75	"New procedure increases required mental effort - would probably get better with exposed use."
6. How do you feel the ITC procedure will effect the controller's workload?	"I feel that it will in general have little effect. The procedure can only be applied in a limited number of cases." "With proper training/implementation, it should be OK." "I feel that in general, this should have minimal effect on the controller's workload." "If you don't change controller's responsibilities and brief controllers properly, including practice problems, it should not effect workload much - it's just another tool."		
7. If you were a relieving controller, was it apparent that an ITC maneuver had taken place?	Yes 4	No 0	

* Yes/No questions: There were a total of 4 forms (2 controllers X 2 days), resulting in 4 total answers.
** R4: Ratings for question 4 ranged from 1 (very low) to 5 (very high).
*** R5: Ratings for question 5 ranged from 1 to 10 based on the MCH scale

The results in table D-5 indicate that there were some difficulties in the procedure as implemented (questions 1 and 2). However, overall, the controllers had high confidence in its effectiveness and experienced only a low increase in their workload (questions 3, 4, 5, 6, 7).

With regard to the experimental performance measures, the comments indicate that the controllers felt the procedure was safe, practical, and feasible.

D.2.2 Controller Observers.

Two qualified controller observers provided information on the simulation results by filling out Controller Observer Forms. This Form is included in appendix C. The results are summarized in table D-6. The responses to question 5 are given in compact form with all four responses [2 observers X 2 days] shown and averaged.

The results shown in table D-6 illustrate the observer's view of the ITC procedure, as conducted in the Full Mission Simulation Experiment. They indicated there were some minor difficulties in the procedure, but that, overall, they believed the procedure to be safe and practical.

Specifically, the responses to question 1 indicated that, in 3/4 of cases, the controller was given adequate information to perform the procedure. Occasionally (#6 comments), the pilots did not follow the procedure or did not provide enough information to the controller.

In one case, a controller issued the ITC clearance in error. This was during Day 2 of the simulation during Condition 4, where the two aircraft had a high (.03) assigned Mach number difference. This should have precluded the clearance being granted.

The observers also noted the controller's ability to adapt existing techniques to accommodate the ITC procedure. For example, on several occasions a conflicting aircraft was given a climb or assigned a new speed to accommodate the ITC request. In general, the controller was able to accommodate all but one request out of the 12 attempts.

D.2.3 Controller Results Summary.

In summary, the following are indicated by the data:

a. Controller workload connected with the ITC procedure in a realistic environment was considered to be average. This was based on the controllers using their experience of average workload levels at Oakland ARTCC as a basis. There was no indication of a significant increase in workload (according to quantitative results and verbal reports) due to the addition of the ITC procedure.

b. In general, the controller received sufficient information to safely conduct the ITC procedure if the pilots followed the checklist and used proper phraseology. Some confusion resulted if the procedure was not followed properly.

c. The strip markings to support the ITC procedure were sufficient for controllers and for relief controllers to understand that an ITC had occurred.

d. In cases where applicability rules were not met, the controllers were able to recognize this and react appropriately. Significantly, the controller was able to use his/her familiarity with existing techniques to accommodate ITC requests that otherwise may not have been allowed. In one case the applicability rules were not followed, possibly indicating a weakness in the controller training process.

e. Overall there was strong confidence that the ITC procedure was safe, practical, and feasible.

TABLE D-6. CONTROLLER OBSERVER FORM RESULTS

Question	Responses		Comments
1. Was the controller given adequate information to perform the ITC procedure?	Yes = 19	No = 3	19/24 Yes = 79 % (2 missing answers.)
2. What was the reported distance to the lead aircraft?	(N/A)	(N/A)	Distance not reported on one of 12 occasions. For all others the distance reported was >15 nmi.
3. Was the climb: A - Approved or D - Disapproved?	<u>Condition</u> 1 2 3 4 5 6	<u>A or D*</u> A/A A/D A/A A/A A/A A/A	 Nominal, OK. Moved conflicting traffic first. Corrected mis-identification. Should have disapproved (2).
4. Did the controller follow the procedure as outlined?	Yes = 20	No = 2	2 blanks. The Day 2 Condition 4 ITC was approved and should not have been.
5. Give a workload rating for the controller (for each condition). Rating is from 1-5, 1 = very low, 5 = high. (The responses to question 5 are shown in a compact form with all four responses [2 observers X 2 days] shown and averaged.)	<u>Condition</u> 1 2 3 4 5 6	 3,2,3,1 3,4,4,1 2,4,3,1 3,3,3,1 2,_,3,_ 3,_,_,_ Avg.: 2.6	 "One minute to issue clearance." "Controller ingenuity." "No denial, tend to work it out." "Not busy at time of climb." (Underline indicates missing data.)

6. Additional Comments.

1. "Clearance given as DAL161, not DAL161P."
2. "Traffic noticed after 10 sec, NWA355 called to ask when he could take higher. Pilot made to second guess controller. Alternate action taken [in Condition 2] and climb approved."
3. "Controller caught missed call sign, then queried pilots [in Condition 3]."
4. "Several of the conditions required the controller to grant a speed change clearance. Is a speed assignment needed?"
5. "When the aircraft reports unable climb [Condition 5], is it required to restate the altitude when the aircraft never received clearance?"
6. "In some cases the pilot's checklist was not followed."
7. "Condition 1: DAL161 and DAL161P inadvertently mis-identified."
8. "Condition 2: Controller moved conflicting traffic then climbed DAL25."
9. "Condition 3: Controller caught call sign error."
10. "Condition 4: DAL80 requested to slow to perform ITC. Controller complied."
11. "Condition 5: Aircraft unable to climb due to planned delay."
12. "Condition 6: Controller was going to disapprove due to lack of information - which then came in a second message. Controller could then approve. There was some confusion on the controller's part during the emergency."
13. "There was some confusion on controller's part due to use of approximate distance and 'non-standard phraseology'."
14. "Pilot did not follow procedure."
15. "Controller caught call sign error and required re-identification, ITC then approved."
16. ".03 Mach faster behind - not similar speeds."

* Approved or Disapproved for Day 1/Day 2. (6 conditions X 2 days X 2 observers = 24 responses.)

D.3 Debriefing Analysis.

After each day of simulation, a discussion for all study participants was conducted at the FAA Technical Center HFL briefing room. In addition, after the first day of simulation, a separate controller debriefing was held at the ODF. After it was completed, the controllers joined the general discussion in the HFL. On the second day, a single combined debriefing was conducted. This section summarizes these discussions and the resulting recommendations.

D.3.1 March 17, 1994 (Day 1) Controller Debriefing.

The controllers stated they felt the simulation went very well. They commented that the traffic load was reasonable, but that the traffic complexity was relatively low. This referred to the low number of instances of crossing, overtaking, or conflicting aircraft. They recommended that traffic complexity be increased in future ITC simulations.

Another recommendation was that ITC procedure training be clarified to indicate clearly that the climb aircraft must start at the minimum vertical separation (e.g., 2000 ft), but that it may climb to altitudes higher than 2000 ft above the lead aircraft.

D.3.2 March 17, 1994 (Day 1) General Debriefing.

The first day's general debriefing was held after the completion of the simulation. The pilots were from United Airlines. The controller group (controllers, observers, and ODF simulation staff) joined the meeting after one hour. Following is a discussion of the highlights of the debriefing in chronological order.

a. The pilots commented that the situation in which another (not the lead) aircraft was above and behind them was not covered in the training. In general, they said that several items covered in the introduction to the training material should be included on the actual cockpit checklist.

b. The pilots also recommended several other items to add to the checklist:

1. The correct phraseology for the ITC procedure.

2. Questions to ask the lead aircraft with regard to notification of changes (i.e., ground speed, heading, or altitude).

3. Specifics of the 15 nmi initiation rule and all other critical parameters. (The reference to a minimum of 10 nmi was not clear. Was this a minimum limit, or an advisory that if the climb aircraft did close to within 10 nmi there was a problem? The pilots emphasized the need for clearly stated absolute limits.)

4. Clarify the 30 degree offset limit on the checklist.

5. Add the ITC checklist to the other flight checklists.

6. Add recommended actions for contingency situations to the checklist (i.e., engine out, lack of climb performance, turbulence, severe weather).

c. There was a consensus that the ITC procedure was generally sound. It was easy to accomplish and would be beneficial.

d. Even in the worst case engine-out condition, the lead aircraft would have to practically stop to be a factor of concern.

e. Training: The flight crew suggested using a 5-minute video tape to assist with training. They emphasized that the video tape would do in 5 minutes what a large bulletin could not, due to the visual nature of pilot learning. They stated clearly that use of the Pilot Training Bulletin alone was not sufficient for ITC training. They suggested LOFT or CBIT training would be beneficial, but that crews should not be required to return to training centers for ITC training.

At this point the controllers joined the debriefing and the attention shifted to their opinions of the procedure. The controllers:

a. Stated that the procedure quickly became routine after an initial familiarization stage.

b. Stated that the simulation was very realistic and valid.

c. Recommended giving practice problems to newly initiated controllers as the best way to familiarize them with the ITC procedure.

d. Raised the possibility that an untrained pilot may hear another pilot requesting an ITC and attempt the same request.

e. Recommended adopting a specific term or method to identify the ITC procedure. Several alternatives were discussed and the term ITC was settled on at least for now.

It was suggested that controllers, when forced to deny ITC requests, also provide information about why the request was denied.

D.3.3 March 18, 1994 (Day 2) General Debriefing.

The debriefing for the second day of ITC simulation was held shortly after the simulation was completed. The pilots (from Delta Airlines) stated the following:

a. They would feel comfortable using the ITC procedure.

b. They recommended that a short briefing should be added to supplement the Pilot Training Bulletin.

A discussion developed concerning the worst case condition (#6) in which the lead aircraft lost an engine and turned off-track. It was suggested that it may be possible to create an even worse (yet still feasible) case in which the aircraft is initially off-track to the left. Then, if it also loses an engine and turns right to move off-track, it may come closer to the climb aircraft than the recommended 10 nmi minimum. It was recommended that a brief study of this possibility be conducted.

Another discussion developed concerning protected airspace. The pilots stated that they felt they had the option of discontinuing the climb and returning to their original altitude in case of a

problem. They felt they "owned" the original altitude (e.g., FL320) until they reached the cleared altitude (e.g., FL360). Controllers stated that since the aircraft was cleared to climb to FL360, the pilot no longer was cleared for the original altitude. However, most controllers would protect that altitude until they received notification that the climb aircraft had reached the newly assigned altitude.

A suggestion was made to include key items from ATC on the cockpit ITC checklists, and vice versa. It was thought that the added information would help the pilot and controller in their own tasks. For example, if the pilot knows that the controller is going to check the target altitude for other aircraft within a 10 minute longitudinal separation, it might help in the pilot's understanding of the process.

It was recommended that the phrase "ITC" be included on both controller and pilot checklists.

D.3.4 Debriefing Results Summary.

The following points summarize the debriefings:

a. The controllers felt the simulation was very realistic and represented current conditions at Oakland ARTCC. They recommended that while the traffic load was realistic, traffic complexity should be somewhat higher.

b. Controllers and pilots recommended that training be clarified and all important parameter values be included in training and checklists. It was also widely recommended that training include a short video to supplement the Pilot Training Bulletin.

c. Several items were recommended for addition to the cockpit checklist.

d. Both controllers and pilots agreed that the procedure was relatively simple to execute and that, with minor adjustments to training and checklists, it would be safe and practical. The effect on workload was expected to be minimal.

D.4 Quantitative Data Analysis.

This section summarizes the numerical data analysis for each ITC condition. Each of the six conditions was nearly identical on the two days and is grouped together in this discussion. For each condition, a series of three graphs is shown which summarize the key parameters of the simulation. These parameters include:

a. Range between aircraft (in nautical miles).
b. Altitude and climb rate of the climb aircraft (in feet and feet per minute).
c. Relative bearing angle from the climb aircraft to the lead aircraft (in degrees).

Condition 6, (on both days) was somewhat different because of the simulated engine failure. Therefore, additional analysis plots are presented for this condition.

The key limits for initiation of an ITC maneuver were:

a. Initial range between the aircraft (greater than 15 nmi, within TCAS range).
b. Minimum range between the aircraft (suggested no less than 10 nmi).

c. Initial rate of climb performance (500 feet per minute required).
d. Initial relative bearing angle at the start of the climb (less than 30 degrees left or right).

All of the numerical data discussed here are presented in appendix E.

D.4.1 Condition 1: Nominal Case.

Figure D-1 shows the key parameters of the nominal case for Day 1. The first graph in the figure shows the range between the two aircraft. (All times in these graphs are simulation time.) The range started at 20 nmi, and gradually decreased due to the initial closing rate.

The second graph in figure D-1 shows the altitude and climb rate of the climb aircraft as a function of time. Altitude is plotted using the left axis and climb rate is on the right axis. The climb took approximately 7 minutes to complete. The climb rate started at 800 fpm and then decreased to 400 fpm.

The third graph in figure D-1 shows the relative bearing of the lead aircraft with respect to the climb aircraft. The bearing angle started at approximately 2 degrees and gradually increased to 5 degrees.

Figure D-2 shows the same parameters for the Day 2, Condition 1 simulation. The Day 2 nominal condition was somewhat different. The range started at 19 nmi, and decreased to almost 15 nmi before the climb was initiated. A special clearance was granted to the aircraft to decrease its speed to the same Mach as the lead aircraft during the climb. The effects of this can be seen in the flattening of the range graph in figure D-2. (After the climb aircraft reduced speed, the range remained constant.)

The altitude graph in figure D-2 shows that the climb started with an initial rate of 800 fpm, and then increased to 1000 fpm for one minute before decreasing to 800 fpm and then 600 fpm. The climb took approximately 6 minutes to complete. In this case, the relative bearing between the aircraft was maintained at 5 degrees for almost the entire condition.

Both Day 1 and Day 2, Condition 1 runs were successfully completed according to the procedure because the range at the start of the climb was greater than 15 nmi and did not decrease below 10 nmi. In addition, the initial climb rate was greater than 500 fpm and the initial bearing angle was less than 30 degrees at all times.

D.4.2 Condition 2: Interfering Traffic.

Figure D-3 shows the key parameters for Day 1, Condition 2. The first of the three graphs in the figure shows the range between the two aircraft. The range started at 18 nmi, and gradually decreased due to the initial closing rate. The range between the aircraft was always greater than 16 nmi. The second graph in figure D-3 shows the altitude and climb rate of the climb aircraft as a function of time. The climb began at 2:19 and lasted for 5 minutes. The climb rate started at 800 fpm and was maintained throughout the climb.

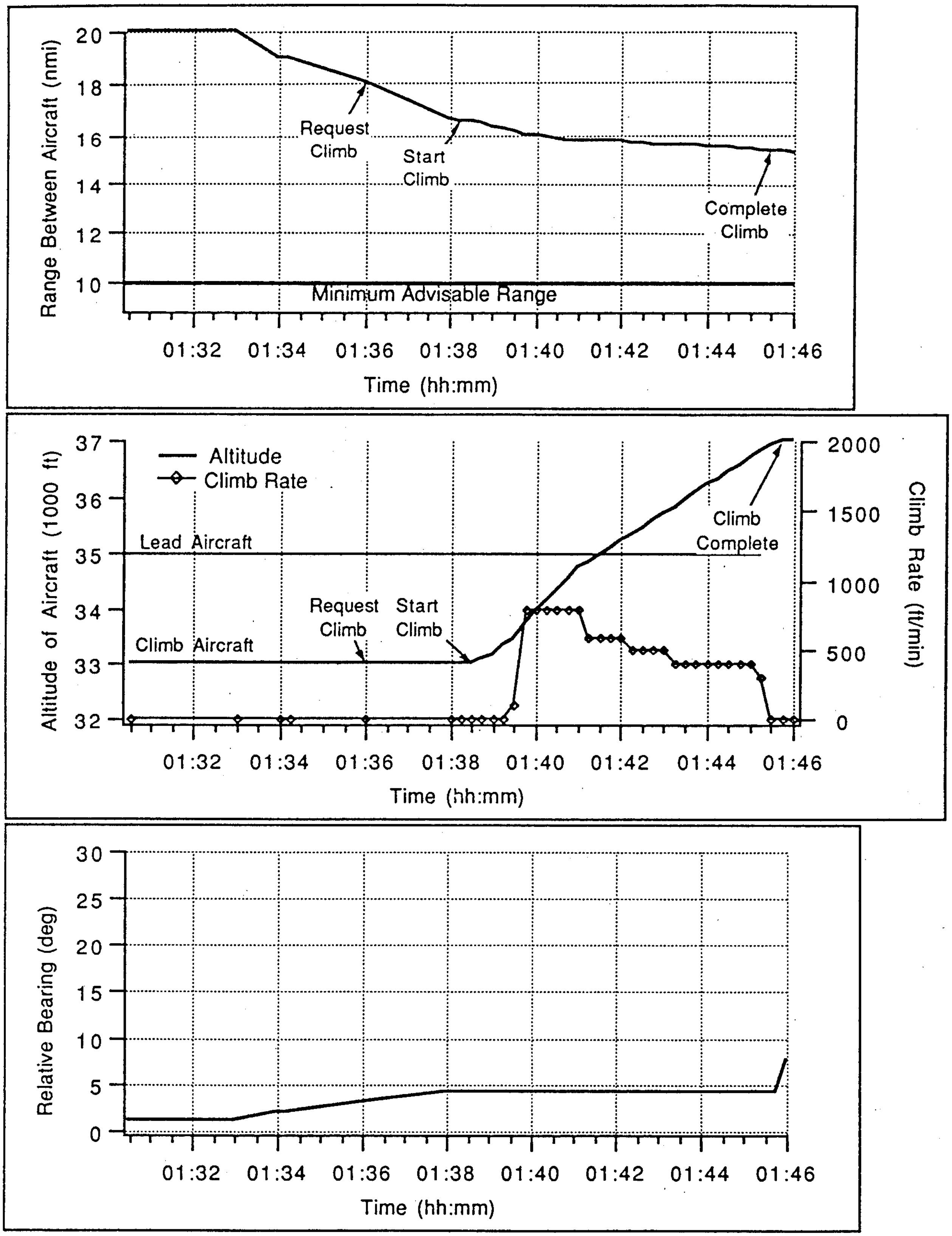

FIGURE D-1. DAY 1, CONDITION 1 NOMINAL CASE KEY PARAMETERS

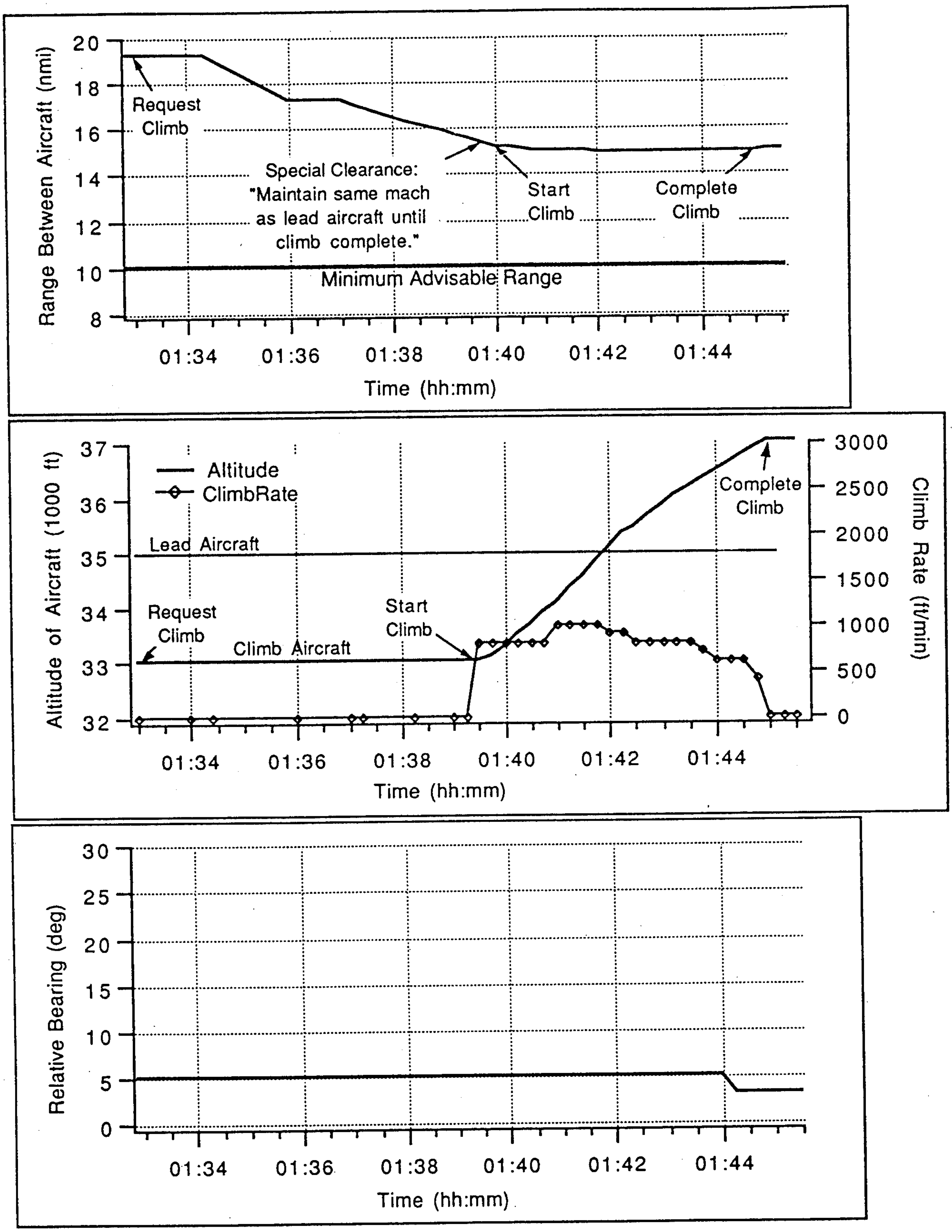

FIGURE D-2. DAY 2, CONDITION 1 NOMINAL CASE KEY PARAMETERS

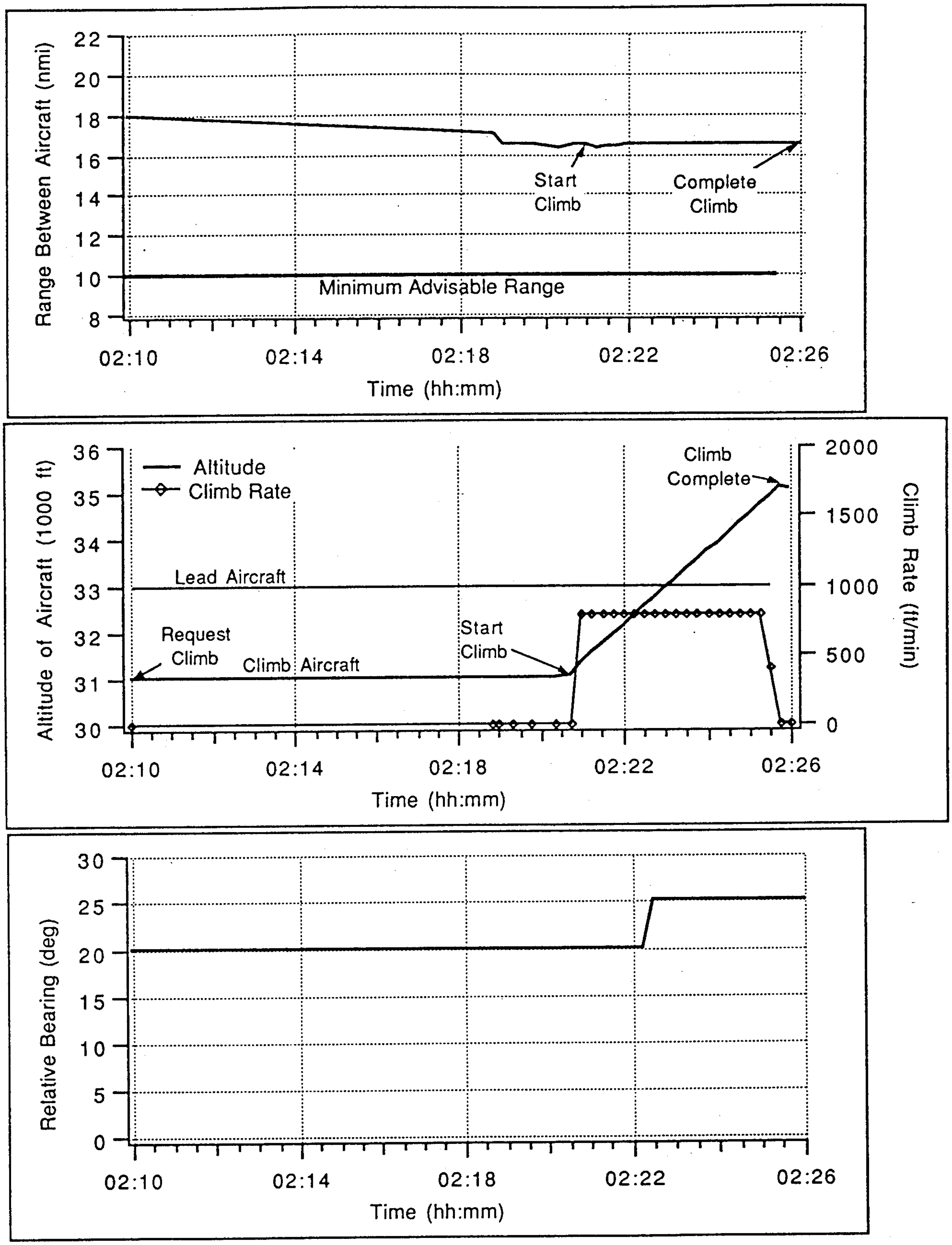

FIGURE D-3. DAY 1, CONDITION 2 INTERFERING TRAFFIC KEY PARAMETERS

The third graph in figure D-3 shows the relative bearing of the lead aircraft with respect to the climb aircraft. In this case the bearing angle started at 20 degrees and increased to 25 degrees (always staying below 30 degrees).

The Day 1, Condition 2 run was successful because the interfering traffic at the requested altitude was moved by the controller before granting the normal ITC clearance. The range at the start of the climb was greater than 15 nmi, and did not decrease below 10 nmi. In addition, the initial climb rate was greater than 500 fpm and the initial bearing angle was less than 30 degrees.

The graphs in figure D-4 show the key parameters for Day 2, Condition 2. The range started at approximately 22 nmi and decreased to almost 20 nmi before the clearance was refused. The controller refused the clearance because of traffic at the requested altitude. The relative bearing between the aircraft was 0 degrees throughout the simulation.

The Day 2, Condition 2 run was also a success because the controller did not grant the clearance due to the traffic at the requested altitude. This was an acceptable action according to the procedure.

D.4.3 Condition 3: Mis-Identified Leading Aircraft.

Figure D-5 shows the simulation parameters for Day 1, Condition 3. The first of three graphs in the figure shows the range between the two aircraft. The range started at 27 nmi, and gradually decreased due to the initial closing rate. The range was never below 25 nmi.

The second graph in figure D-5 shows the altitude and the climb rate of the climb aircraft as a function of time. The climb began at 2:36 and lasted for 7 minutes. The climb rate started at 800 fpm and later decreased to 400 fpm.

The third graph in figure D-5 shows the relative bearing of the lead aircraft with respect to the climb aircraft. In this case, the bearing angle started at 2 degrees and later increased to 5 degrees, well within the 30 degree limit.

The graphs in figure D-6 show the same parameters for Day 2, Condition 3. The range started at 19 nmi, and decreased to almost 18 nmi before the climb commenced. The relative bearing between the aircraft was 0 degrees throughout the simulation.

Both Day 1 and Day 2, Condition 3 runs were successful because the controller noticed the mis-identification of the lead aircraft, and then was able to grant the clearance after the error was corrected. All required parameter values were met for the procedure. The range at the start of the climb was greater than 15 nmi, and did not decrease below 10 nmi. In addition, the initial climb rate was greater than 500 fpm and the initial bearing angle was less than 30 degrees.

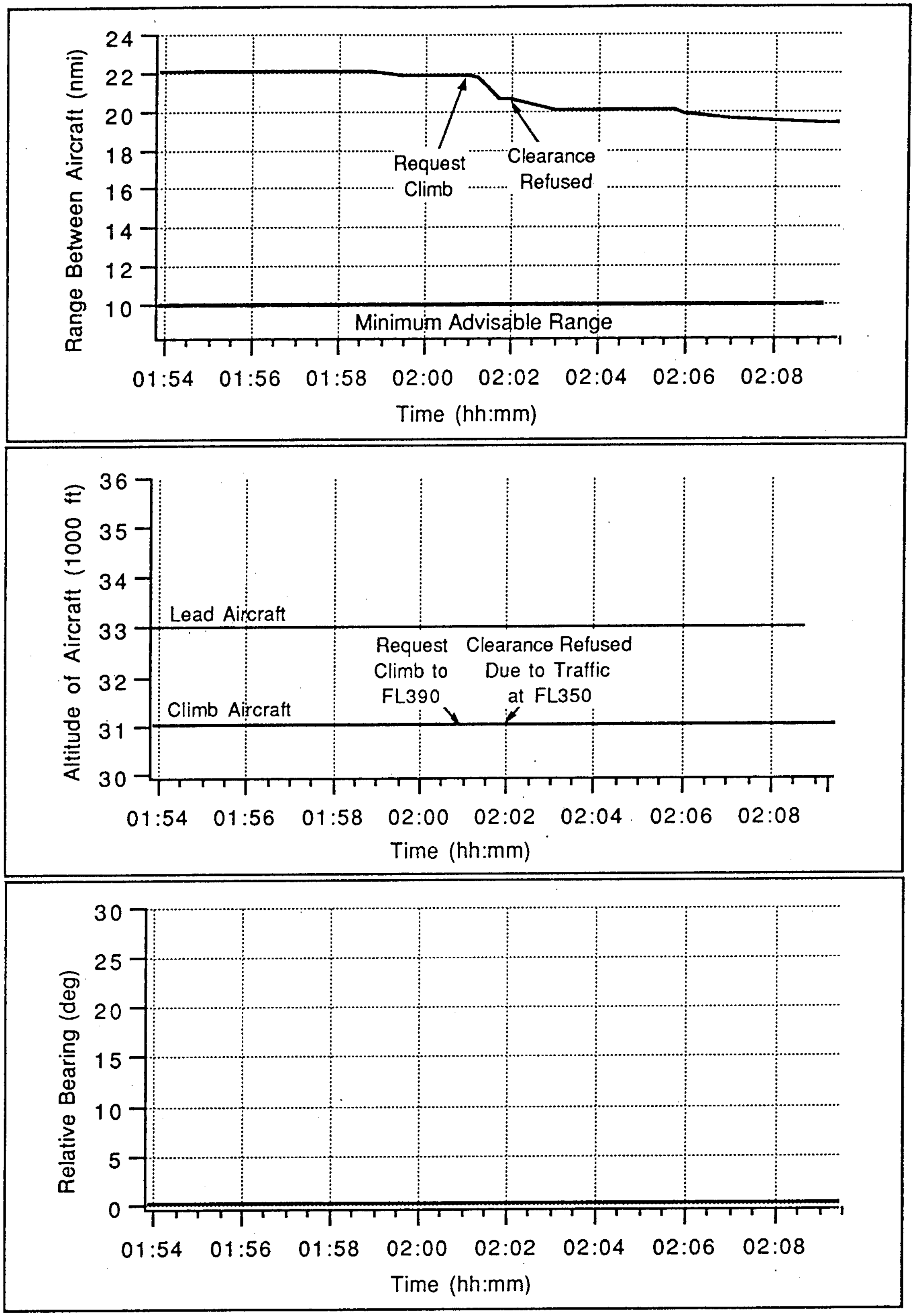

FIGURE D-4. DAY 2, CONDITION 2 INTERFERING TRAFFIC KEY PARAMETERS

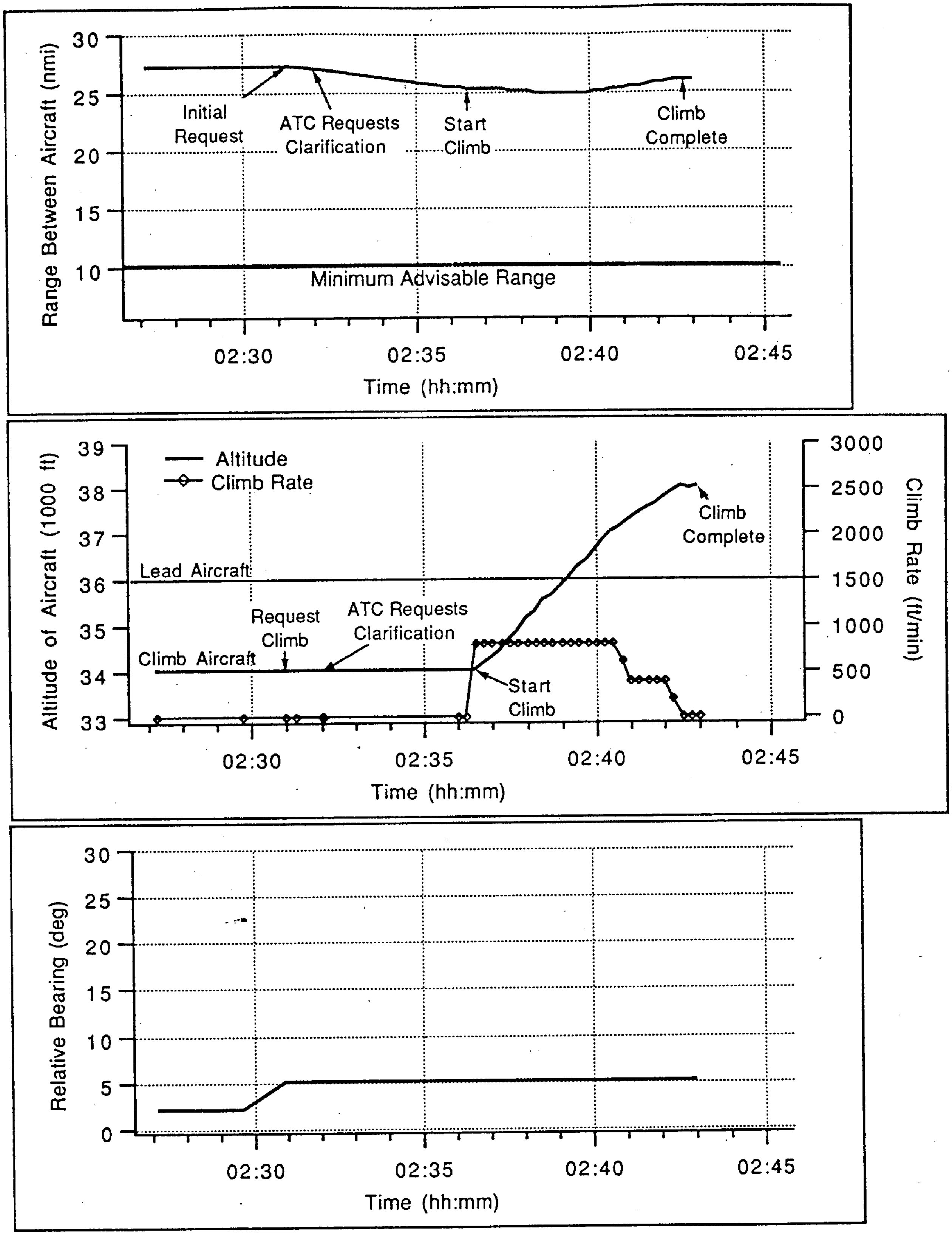

FIGURE D-5. DAY 1, CONDITION 3 MIS-IDENTIFIED TRAFFIC KEY PARAMETERS

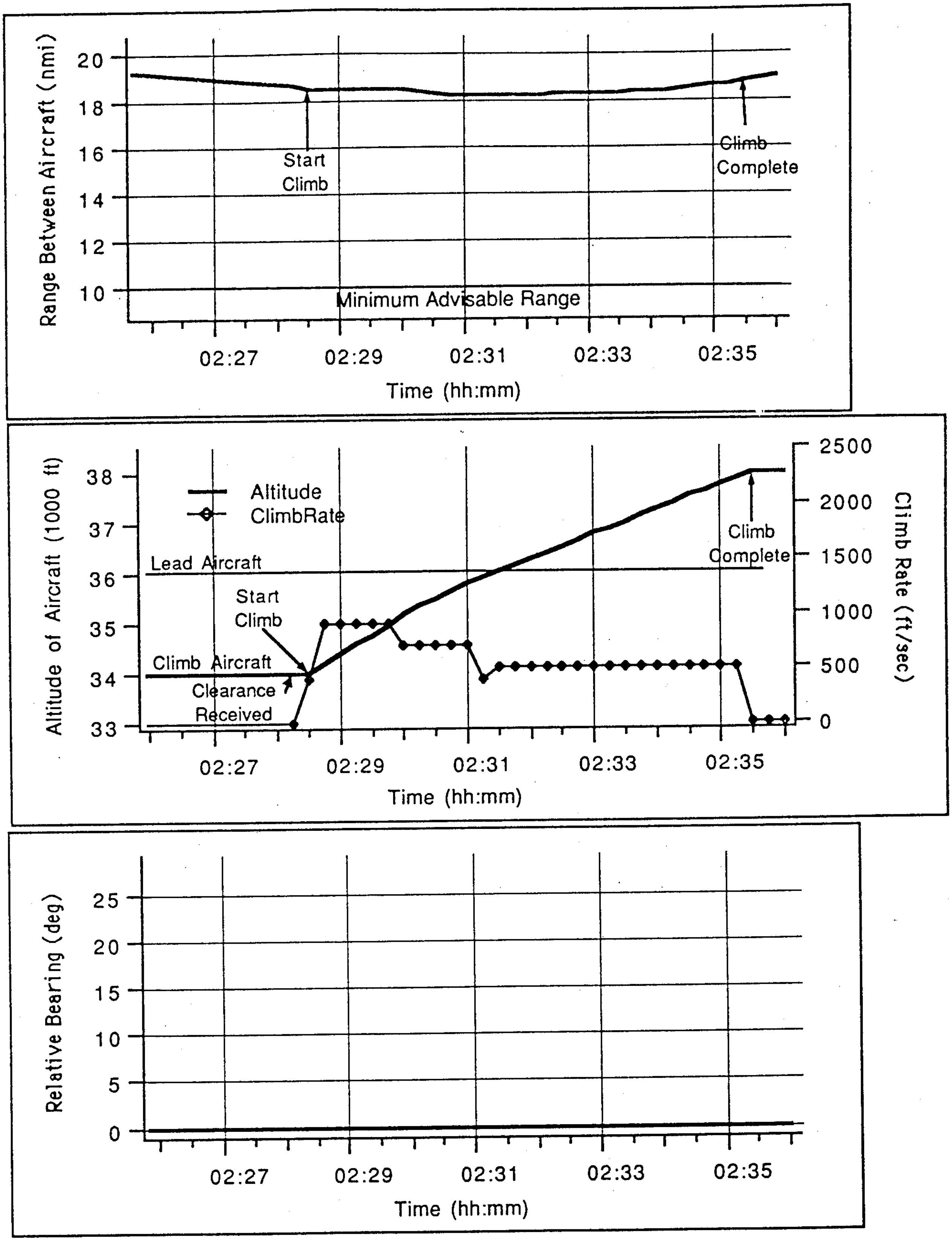

FIGURE D-6. DAY 2, CONDITION 3 MIS-IDENTIFIED TRAFFIC KEY PARAMETERS

D.4.4. Condition 4: Closure Rate Too High.

Figure D-7 shows the key parameters for Day 1, Condition 4. The first graph indicates the range between the two aircraft. The range started at 17 nmi, and gradually decreased due to the initial closing rate. The range came very close to the 15 nmi limit before the climb was initiated, and then decreased below 15 nmi after the climb started. Thus the climb started before the 15 nmi limit was reached.

The second graph shows the altitude and the climb rate of the climb aircraft as a function of time. The climb began at 3:03 and lasted for 5 minutes. (Data collection was discontinued just before reaching the top of climb due to time constraints during the simulation.) The climb rate started at 800 fpm, later increased to 1000 fpm, and finally decreased to 900 fpm.

The third graph in figure D-7 shows the relative bearing of the lead aircraft with respect to the climb aircraft. The bearing angle was 0 degrees throughout the simulation.

The graphs in figure D-8 show the same parameters for Day 2, Condition 4. The range started at 18 nmi and decreased to almost 17 nmi before the climb started. The climb began at 2:58 and continued until 3:04 (6 minutes). The climb rate was at 900 fpm and later decreased to 800, 700, and then 500 fpm. The relative bearing between the aircraft was 0 degrees throughout the simulation.

The Day 1, Condition 4 run was successful because the controller reduced the speed of the climb aircraft (to avoid the high Mach closure problem) and then approved the climb. Thus the controller conformed to the Mach closure limit built into the ITC procedure. Also, the range at the start of the climb was greater than 15 nmi, and did not decrease below 10 nmi. The initial climb rate was greater than 500 fpm and the initial bearing angle was less than 30 degrees.

The Day 2, Condition 4 run was the only unsuccessful run because the controller approved the ITC without modifying the too-high Mach difference between the two aircraft (see appendix C). In this case, the aircraft were still safely separated, and all other parameter requirements of the procedure were met. The range at the start of the climb was greater than 15 nmi, and did not decrease below 15 nmi. The initial climb rate was greater than 500 fpm, and the bearing angle was less than 30 degrees at the start of the climb.

D.4.5. Condition 5: Unable to Climb.

Figure D-9 shows the key parameters for Day 1, Condition 5. The first graph is of the range between the two aircraft. The range started at 15 nmi, and gradually decreased due to the initial closing rate. After the initial clearance request, the range passed below the 15 nmi limit and subsequently, the clearance request was canceled. Thus, the climb was never initiated.

The second and third graphs show the altitude of the climb aircraft. Because the climb was not executed, the altitude remained at FL340, and the climb rate was zero. The relative bearing (shown in the last of the three graphs in figure D-9) stayed at zero degrees.

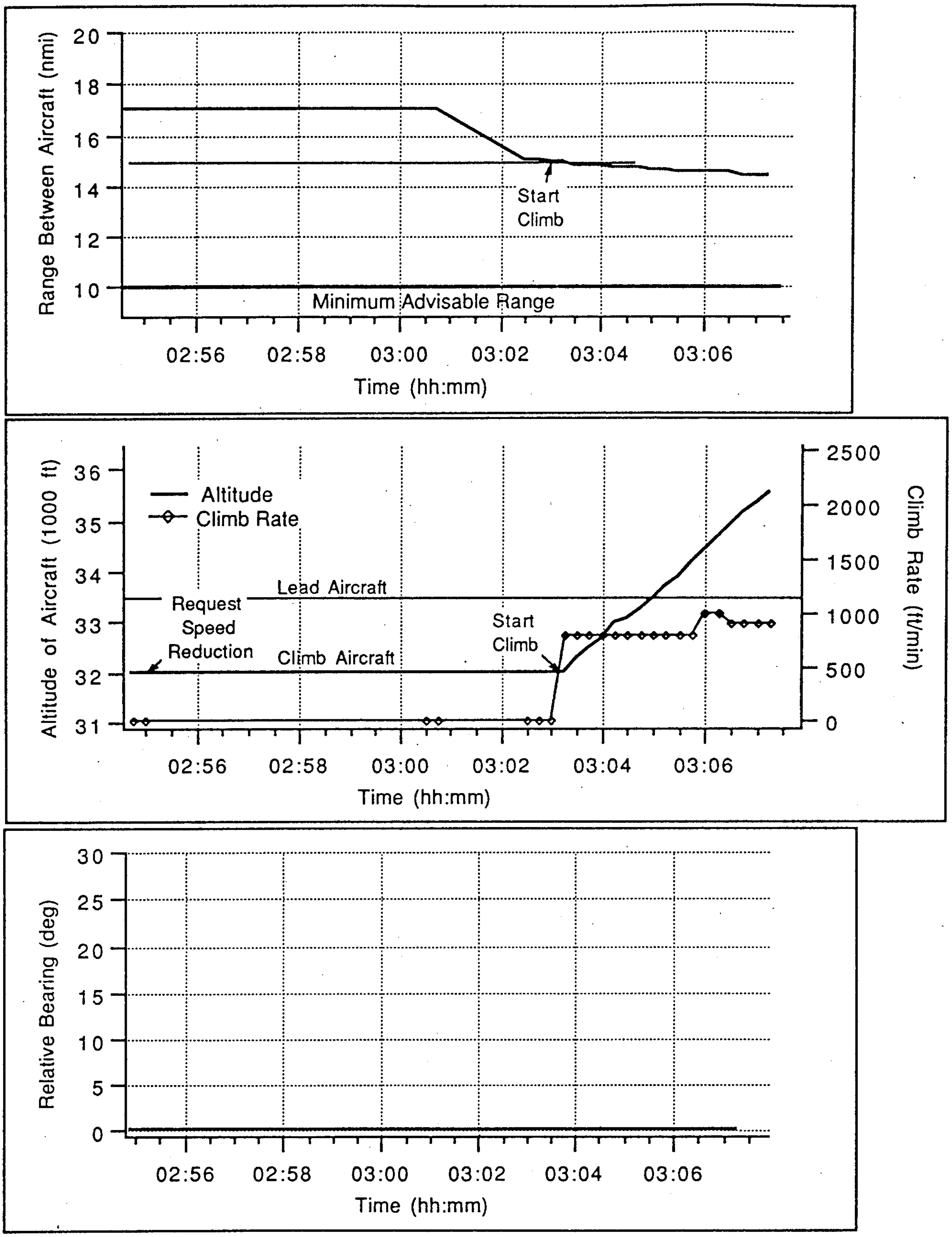

FIGURE D-7. DAY 1, CONDITION 4 HIGH CLOSURE RATE KEY PARAMETERS

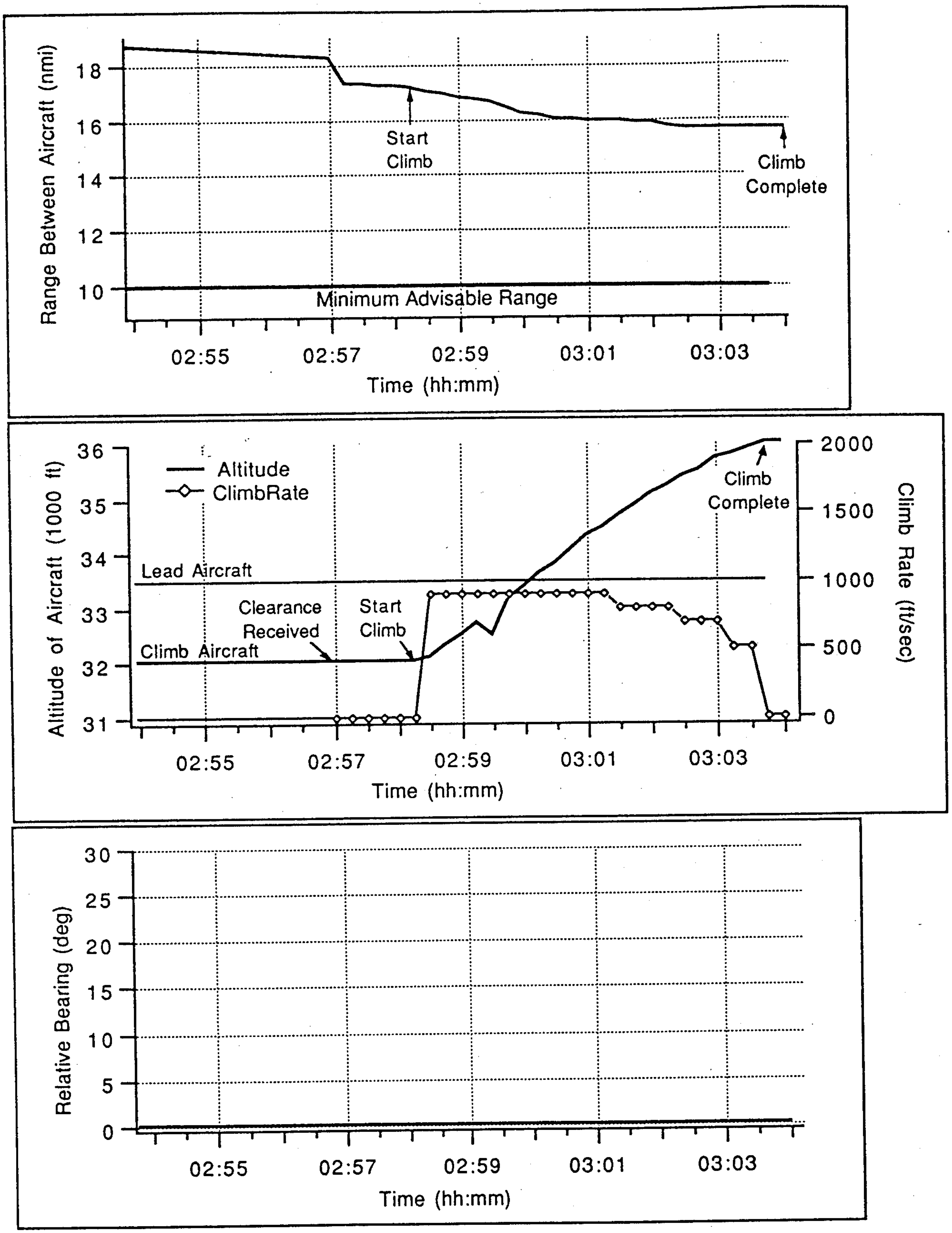

FIGURE D-8. DAY 2, CONDITION 4 HIGH CLOSURE RATE KEY PARAMETERS

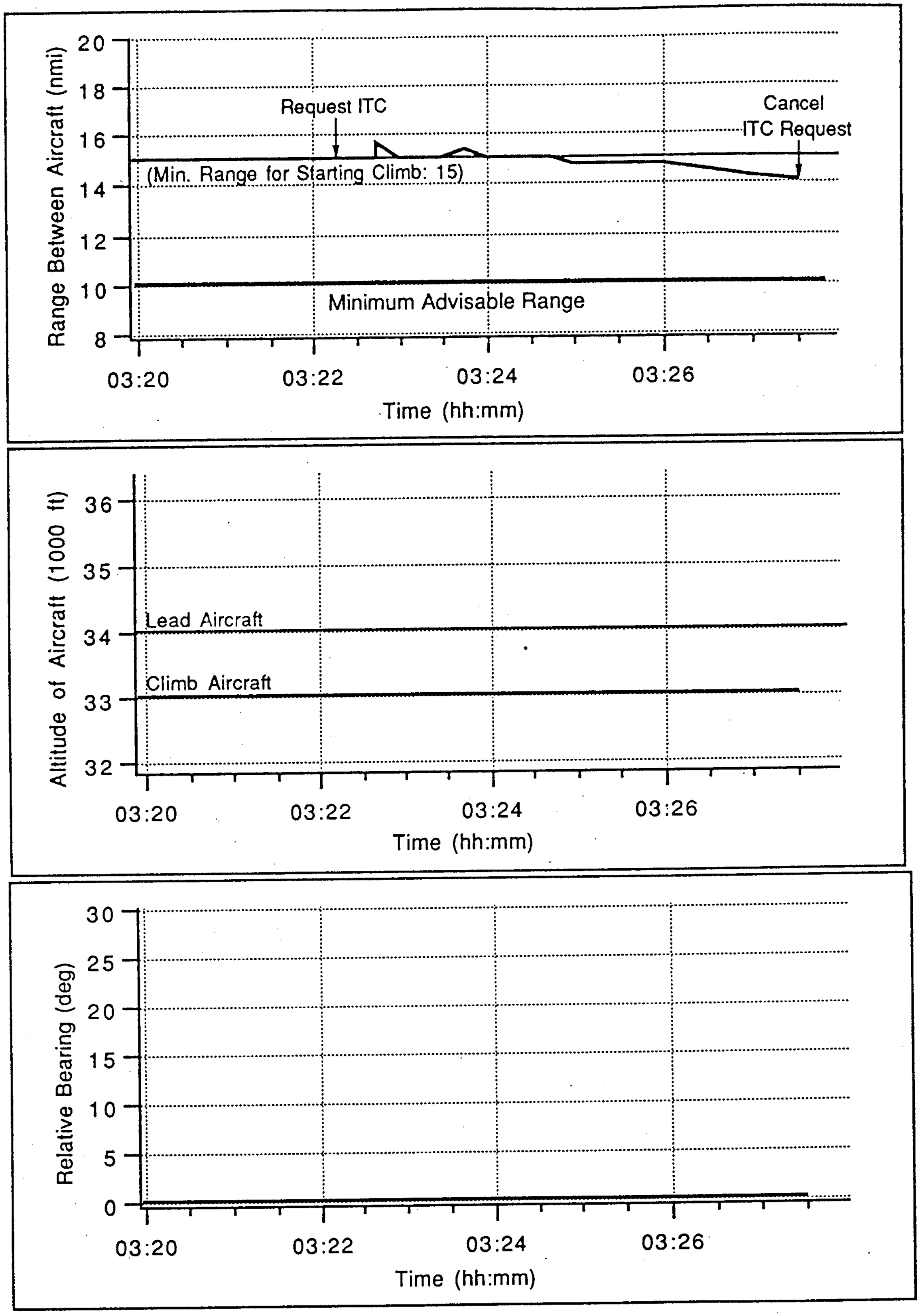

FIGURE D-9. DAY 1, CONDITION 5 UNABLE TO CLIMB KEY PARAMETERS

Figure D-10 shows that the second day was similar to the first for Condition 5. Again, after the ITC request was made, the range gradually decreased below the 15 nmi limit, and the pilot canceled the request.

The second and third graphs in figure D-10 show the altitude of the climb aircraft. Because the climb was not executed, the altitude remained at FL340, and the climb rate was zero. The relative bearing (shown in the last of the three graphs in figure D-10) stayed at zero degrees throughout most of the condition, but briefly went to 10 degrees. This is believed to be an anomaly in the data collection process.

Both Day 1 and Day 2, Condition 5 runs succeeded because requests for the ITC were canceled on both days due to the unacceptably low initial range, in compliance with the ITC procedure. The range became less than 15 nmi after the initial request and before the clearance was received. After observing this, both cockpit crews correctly decided to cancel their requests for an ITC.

D.4.6. Condition 6: Engine Out.

Condition 6 involved an engine out situation in the lead aircraft. At the same time, the lead aircraft's TCAS transponder became inoperable. Since some of the numerical data were collected from the video recording of the TCAS screen (range and bearing to the lead aircraft), these data were not available. To recreate the missing data, a separate simulation was run with the same basic characteristics, initial conditions, and timing. The data shown here and presented in tables E-6 and E-12 in appendix E are from this independent simulation.

Figure D-11 shows the key parameters of the simulation for Day 1, Condition 6. The first of the three graphs shows the range between the two aircraft. The range started at 22 nmi and gradually decreased due to the initial closing rate. The range decreased to 21 nmi at the start of the climb. After the engine out on the lead aircraft, the range began to decrease rapidly because of the emergency procedure right turn off-track. The range decreased to a minimum of 16.5 nmi before the two aircraft began to diverge.

The second graph shows both the altitude of the climb aircraft and the lead aircraft as a function of time. The climb began at 3:48 and continued to 3:53 (5 minutes). The altitude of the lead aircraft decreased shortly after the start of the ITC due to the engine failure. The lead aircraft descended to FL270 while the climb aircraft ascended to FL360. The lead aircraft was approximately 21 nmi ahead when it reached the altitude of the climb aircraft (the co-altitude point).

The third graph in figure D-11 shows the relative bearing of the lead aircraft with respect to the climb aircraft. In this case, the lead aircraft turned off-track due the engine failure. The bearing angle reflected this by increasing from zero to 90 degrees and beyond. (Ninety degrees indicates the lead aircraft was off the right wing of the climb aircraft. This was where the climb aircraft passed the lead.)

The graphs in figure D-12 show the same parameters for Day 2, Condition 6. The results were similar except for a hesitation during the climb of the climb aircraft and a slight left turn by the

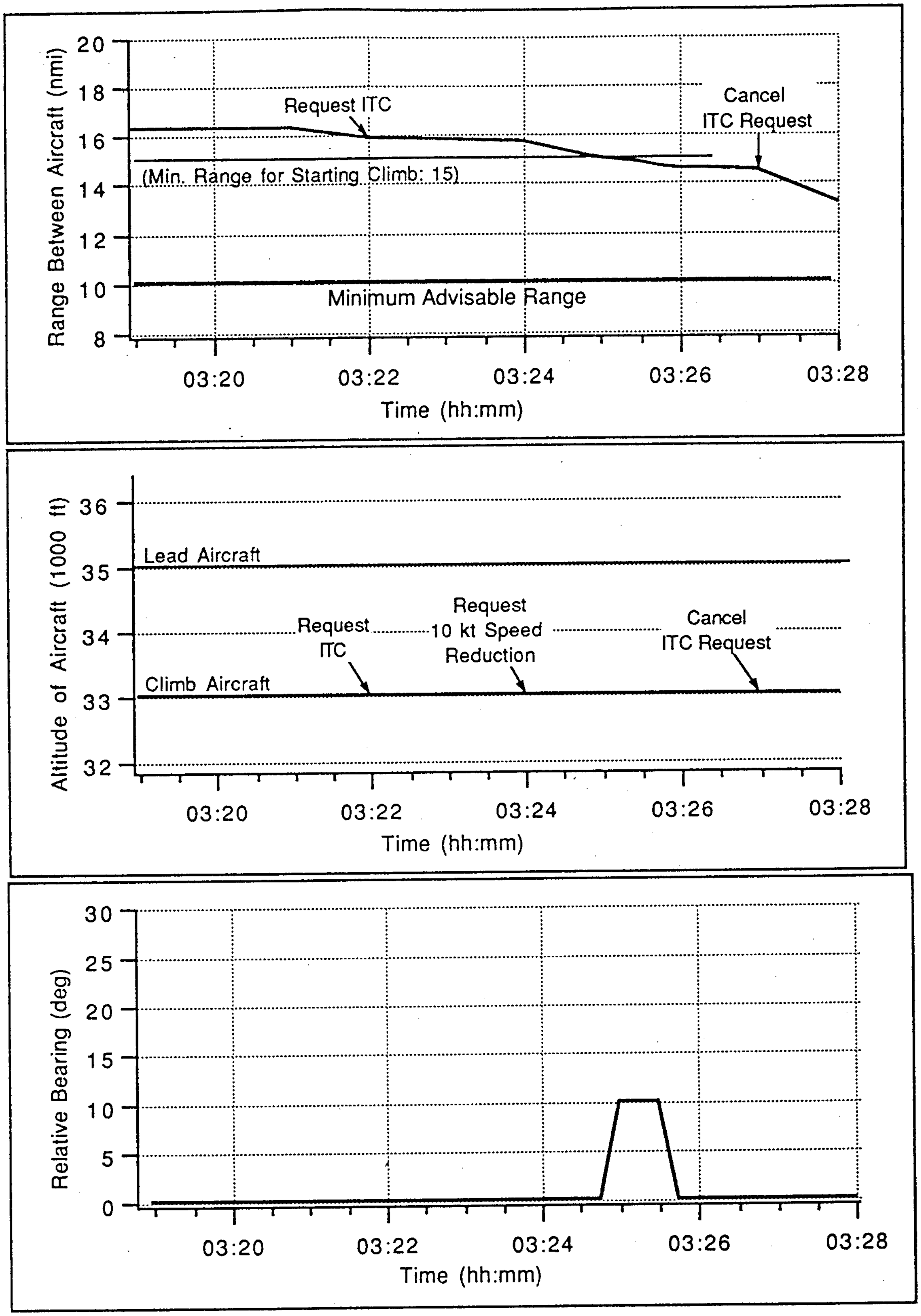

FIGURE D-10. DAY 2, CONDITION 5 UNABLE TO CLIMB KEY PARAMETERS

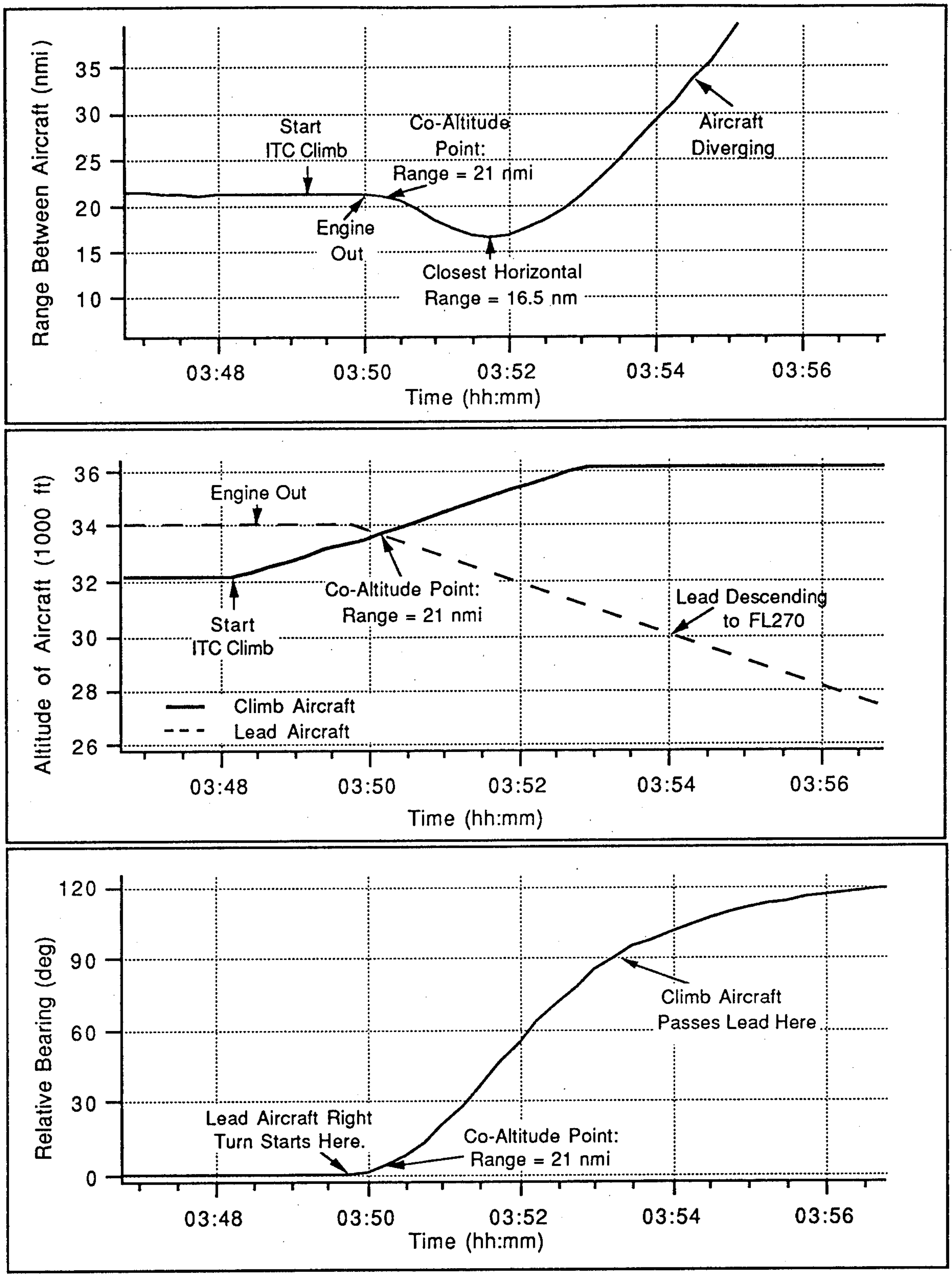

FIGURE D-11. DAY 1, CONDITION 6 ENGINE OUT KEY PARAMETERS

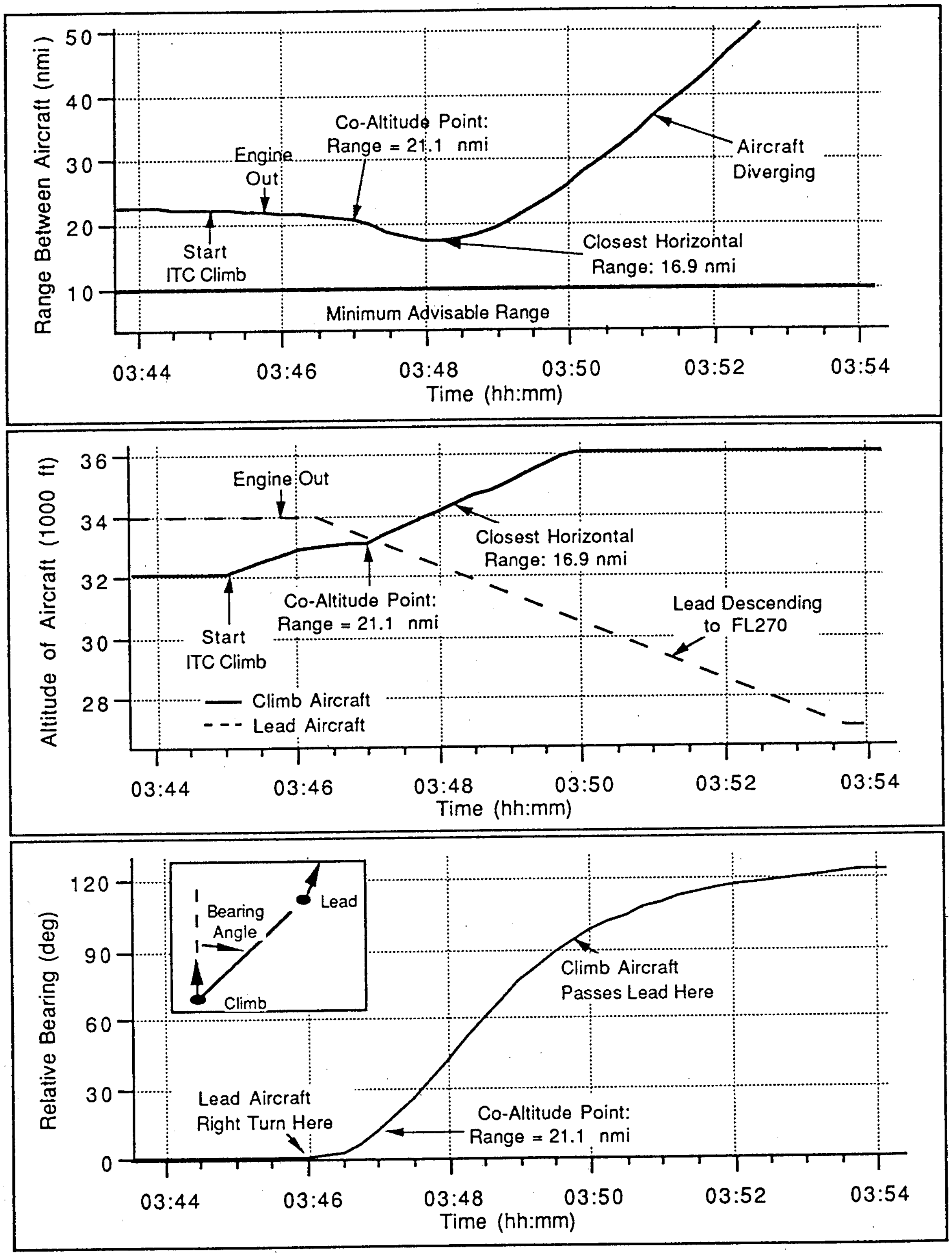

FIGURE D-12. DAY 2, CONDITION 6 ENGINE OUT KEY PARAMETERS

climb aircraft to avoid the lead aircraft. The range in this case started at approximately 23 nmi, and decreased to 22 nmi before the climb commenced. The second graph shows the altitude of the two aircraft, where the momentary decrease in climb rate can be seen at 3:46:30. The DAL pilot stopped climbing long enough to observe the situation, then resumed the climb when it was clear the lead aircraft was not a problem. The third graph in figure D-12 shows the relative bearing between the aircraft.

Figures D-13 and D-14 give overhead views of Condition 6 on Days 1 and 2, respectively. These figures show the actual positions of the two aircraft versus time on a PVD. The track direction is "up" on the graphs. Both the lead and climb aircraft tracks are plotted, along with three simulation times. These plots show the positions of the aircraft as the lead aircraft turned off track. In the case of Day 2, the plot clearly shows the 11 degree left turn by the climb aircraft. It is also clear from the figures that, in both cases, the two aircraft never came near to each other during the procedure.

Both Day 1 and Day 2, Condition 6 runs were successful because the emergency was handled properly according to normal procedures, and all required parameter values were observed. The range at the start of the climb was greater than 15 nmi and did not decrease below the 10 nmi value even for this "worst case." In addition, the initial climb rate was greater than 500 fpm, and the initial bearing angle was less than 30 degrees.

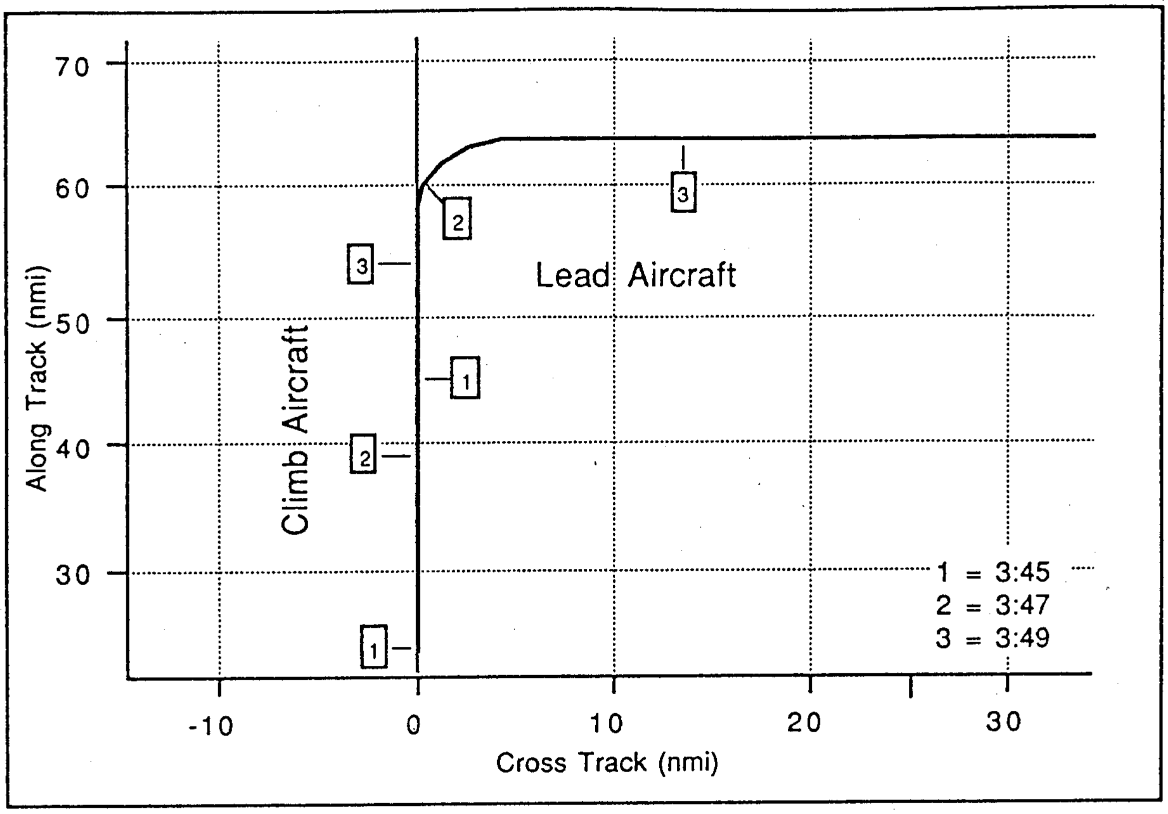

FIGURE D-13. DAY 1, CONDITION 6 PLAN VIEW

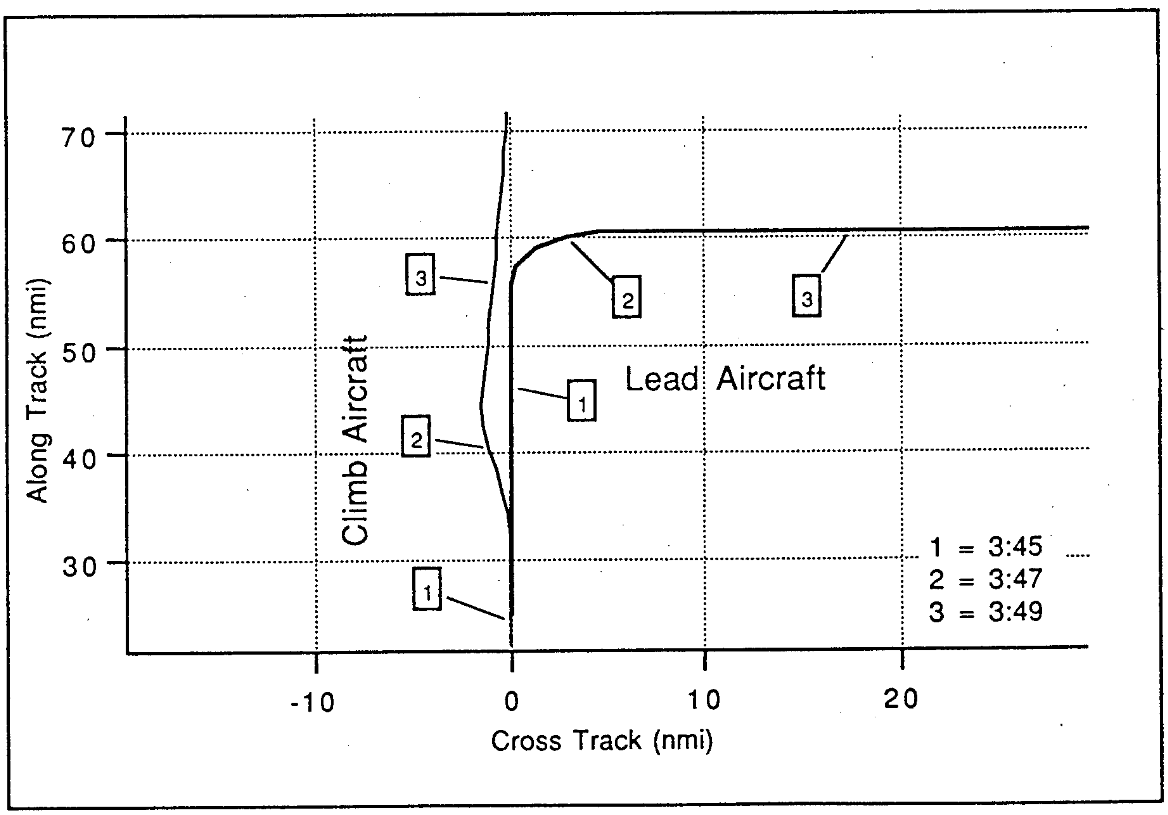

FIGURE D-14. DAY 2, CONDITION 6 PLAN VIEW

APPENDIX E

NUMERICAL RESULTS DATA TABLES

Tables E-1 through E-12 contain the numeric data derived from the video recordings made of the TCAS screen during the ITC simulations. A table is included for each run (6 conditions per day X 2 days = 12 runs total).

TABLE E-1. DAY 1, CONDITION 1 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
01:30:31	20.0	33,021	0	1	0.0	0.860	500	240
01:33:00	20.0	33,021	0	1	0.0	0.860	500	240
01:34:00	19.0	33,021	0	2	0.0	0.860	500	239
01:34:15	19.0	33,021	0	2	0.0	0.860	500	239
01:36:00	18.0	33,021	0	3	0.0	0.860	500	239
01:38:00	16.6	33,021	0	4	0.0	0.858	499	239
01:38:15	16.5	33,021	0	4	0.0	0.858	499	239
01:38:30	16.5	33,021	0	4	0.0	0.858	499	239
01:38:45	16.4	33,075	0	4	0.0	0.858	499	238
01:39:00	16.3	33,142	0	4	0.0	0.855	497	238
01:39:15	16.2	33,343	0	4	0.0	0.853	496	238
01:39:30	16.1	33,442	100	4	0.0	0.850	494	238
01:39:45	16.0	33,742	800	4	0.0	0.848	493	238
01:40:00	16.0	33,941	800	4	0.0	0.845	491	239
01:40:15	15.9	34,141	800	4	0.0	0.843	488	239
01:40:30	15.8	34,330	800	4	0.0	0.840	486	239
01:40:45	15.8	34,522	800	4	0.0	0.838	485	239
01:41:00	15.8	34,743	800	4	0.0	0.837	485	239
01:41:15	15.8	34,835	600	4	0.0	0.837	485	229
01:41:30	15.7	34,959	600	4	0.0	0.838	485	229
01:41:45	15.7	35,086	600	4	0.0	0.837	482	239
01:42:00	15.7	35,209	600	4	0.0	0.837	482	239
01:42:15	15.7	35,330	500	4	0.0	0.837	482	239
01:42:30	15.7	35,452	500	4	0.0	0.837	482	239
01:42:45	15.6	35,578	500	4	0.0	0.837	482	239
01:43:00	15.6	35,702	500	4	0.0	0.837	482	239
01:43:15	15.6	35,823	400	4	0.0	0.837	482	239
01:43:30	15.6	35,950	400	4	0.0	0.837	482	239
01:43:45	15.6	36,080	400	4	0.0	0.837	480	239
01:44:00	15.5	36,223	400	4	0.0	0.837	480	239
01:44:15	15.5	36,320	400	4	0.0	0.836	480	239
01:44:30	15.5	36,441	400	4	0.0	0.836	480	239
01:44:45	15.4	36,569	400	4	0.0	0.834	479	239
01:45:00	15.4	36,694	400	4	0.0	0.832	477	239
01:45:15	15.3	36,812	300	4	0.0	0.830	476	239
01:45:30	15.3	36,935	0	4	0.0	0.828	475	239
01:45:45	15.3	36,995	0	4	0.0	0.830	476	239
01:46:00	15.2	37,000	0	7.5	0.0	0.834	478	239

TABLE E-2. DAY 1, CONDITION 2 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
02:09:00	19.0	31,000	0	20	5.8	0.850	499	232
02:09:10	19.0	31,000	0	20	5.8	0.850	499	232
02:10:00	18.0	31,000	0	20	5.8	0.852	500	232
02:18:50	17.0	31,000	0	20	5.8	0.850	499	231
02:19:00	16.5	31,000	0	20	5.8	0.851	499	231
02:19:20	16.5	31,000	0	20	5.8	0.852	500	231
02:19:45	16.5	31,000	0	20	5.8	0.851	499	231
02:20:20	16.3	30,999	0	20	5.8	0.838	492	231
02:20:45	16.5	31,050	0	20	5.8	0.799	469	231
02:21:00	16.5	31,289	800	20	5.8	0.803	471	231
02:21:15	16.3	31,501	800	20	5.8	0.807	474	231
02:21:30	16.4	31,702	800	20	5.8	0.811	476	231
02:21:45	16.4	31,902	800	20	5.8	0.812	476	231
02:22:00	16.5	32,101	800	20	5.8	0.815	476	231
02:22:15	16.5	32,301	800	20	5.8	0.817	477	231
02:22:30	16.5	32,502	800	25	6.8	0.819	478	231
02:22:45	16.5	32,701	800	25	6.8	0.821	480	231
02:23:00	16.5	32,899	800	25	6.8	0.823	481	231
02:23:15	16.5	33,097	800	25	6.8	0.824	479	231
02:23:30	16.5	33,295	800	25	6.8	0.826	480	231
02:23:45	16.5	33,493	800	25	6.8	0.828	481	231
02:24:00	16.5	33,691	800	25	6.8	0.829	482	231
02:24:15	16.5	33,888	800	25	6.8	0.831	483	231
02:24:30	16.5	34,086	800	25	6.8	0.833	482	231
02:24:45	16.5	34,284	800	25	6.8	0.835	483	231
02:25:00	16.5	34,482	800	25	6.8	0.836	484	231
02:25:15	16.5	34,680	800	25	6.8	0.838	485	231
02:25:30	16.5	34,878	400	25	6.8	0.840	486	231
02:25:45	16.5	35,076	0	25	6.8	0.841	485	231
02:26:00	16.5	35,040	0	25	6.8	0.843	486	231

TABLE E-3. DAY 1, CONDITION 3 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
02:27:15	27.0	34,000	0	2	2.3	0.862	499	46
02:29:45	27.0	34,000	0	2	2.3	0.862	499	46
02:31:00	27.0	34,000	0	5	2.3	0.862	499	46
02:31:15	27.0	34,000	0	5	2.3	0.862	499	46
02:32:00	26.9	34,000	0	5	2.3	0.862	499	46
02:32:05	26.9	34,000	0	5	2.3	0.863	500	46
02:36:00	25.4	34,000	0	5	2.3	0.862	499	46
02:36:15	25.3	34,000	0	5	2.1	0.862	499	47
02:36:30	25.2	34,000	800	5	2.1	0.863	500	47
02:36:45	25.2	34,105	800	5	2.1	0.859	497	47
02:37:00	25.2	34,243	800	5	2.1	0.857	496	47
02:37:15	25.1	34,435	800	5	2.1	0.854	494	47
02:37:30	25.1	34,630	800	5	2.1	0.851	493	47
02:37:45	25.0	34,825	800	5	2.1	0.848	491	47
02:38:00	25.0	35,130	800	5	2.0	0.846	488	47
02:38:15	25.0	35,250	800	5	2.1	0.844	486	47
02:38:30	24.9	35,500	800	5	2.1	0.843	486	47
02:38:45	24.9	35,620	800	5	2.0	0.837	482	47
02:39:00	24.9	35,820	800	5	2.1	0.834	481	47
02:39:15	24.8	36,008	800	5	2.1	0.832	477	47
02:39:30	24.8	36,210	800	5	2.0	0.827	475	47
02:39:45	24.8	36,401	800	5	2.0	0.824	473	47
02:40:00	24.9	36,589	800	5	2.0	0.819	470	47
02:40:15	25.0	36,795	800	5	2.0	0.815	468	47
02:40:30	25.0	36,998	800	5	2.0	0.811	465	47
02:40:45	25.1	37,125	600	5	2.0	0.811	465	47
02:41:00	25.2	37,251	400	5	2.0	0.810	465	47
02:41:15	25.3	37,371	400	5	2.0	0.809	464	47
02:41:30	25.4	37,493	400	5	2.0	0.808	463	47
02:41:45	25.5	37,615	400	5	2.0	0.807	463	47
02:42:00	25.6	37,740	400	5	2.0	0.806	462	47
02:42:15	25.7	37,863	200	5	2.0	0.806	462	47
02:42:30	25.8	37,970	0	5	2.0	0.806	462	47
02:42:45	25.8	37,953	0	5	2.0	0.809	464	47
02:43:00	25.9	37,990	0	5	2.0	0.811	465	47

TABLE E-4. DAY 1, CONDITION 4 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
02:54:15	17.0	32,000	0	0	0.0	0.812	474	47
02:54:45	17.0	32,000	0	0	0.0	0.812	474	47
02:55:00	17.0	32,000	0	0	0.0	0.812	474	47
03:00:30	17.0	32,000	0	0	0.0	0.812	474	47
03:00:45	17.0	32,000	0	0	0.0	0.812	474	47
03:02:30	15.0	32,000	0	0	0.0	0.808	472	47
03:02:45	15.0	32,000	0	0	0.0	0.814	476	47
03:03:00	14.9	32,000	0	0	0.0	0.812	474	47
03:03:15	14.9	32,000	800	0	0.0	0.806	471	47
03:03:30	14.8	32,255	800	0	0.0	0.810	473	47
03:03:45	14.8	32,460	800	0	0.0	0.812	474	47
03:04:00	14.8	32,650	800	0	0.0	0.813	475	47
03:04:15	14.7	32,963	800	0	0.0	0.813	475	47
03:04:30	14.7	33,053	800	0	0.0	0.817	475	47
03:04:45	14.7	33,251	800	0	0.0	0.819	476	47
03:05:00	14.6	33,453	800	0	0.0	0.819	476	47
03:05:15	14.6	33,675	800	0	0.0	0.813	473	47
03:05:30	14.5	33,880	800	0	0.0	0.813	473	47
03:05:45	14.5	34,160	800	0	0.0	0.811	470	47
03:06:00	14.5	34,380	1000	0	0.0	0.811	470	47
03:06:15	14.5	34,650	1000	0	0.0	0.811	470	47
03:06:30	14.5	34,915	900	0	0.0	0.809	468	47
03:06:45	14.4	35,140	900	0	0.0	0.808	466	47
03:07:00	14.4	35,343	900	0	0.0	0.809	466	47
03:07:15	14.4	35,548	900	0	0.0	0.809	466	47

TABLE E-5. DAY 1, CONDITION 5 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
03:11:00	15.0	33,021	0	0	0	0.826	480	219
03:21:45	15.0	33,000	0	0	0	0.861	501	219
03:22:00	15.0	33,000	0	0	0	0.863	502	219
03:22:15	15.0	33,000	0	0	0	0.861	501	219
03:22:30	15.0	33,000	0	0	0	0.859	500	219
03:22:45	15.0	33,000	0	0	0	0.859	500	219
03:22:45	15.6	33,000	0	0	0	0.859	500	219
03:23:00	15.0	33,000	0	0	0	0.860	500	219
03:23:15	15.0	33,000	0	0	0	0.861	501	219
03:23:30	15.0	33,000	0	0	0	0.859	500	219
03:23:45	15.3	33,000	0	0	0	0.857	498	219
03:24:00	15.0	33,000	0	0	0	0.858	499	219
03:24:15	15.0	33,000	0	0	0	0.857	498	219
03:24:30	15.0	33,000	0	0	0	0.858	499	219
03:24:45	15.0	33,000	0	0	0	0.858	499	219
03:25:00	14.8	33,000	0	0	0	0.857	498	219
03:25:45	14.8	33,000	0	0	0	0.858	499	219
03:26:00	14.7	33,000	0	0	0	0.858	499	219
03:27:00	14.2	33,000	0	0	0	0.861	501	216
03:27:30	14.0	33,000	0	0	0	0.864	502	216

TABLE E-6. DAY 1, CONDITION 6 NUMERICAL DATA

Time	Lead X-Track (nmi)	Lead Along Track (nmi)	Lead Altitude (ft)	Climb X-Track (nmi)	Climb Along Track (nmi)	Climb Altitude (ft)	Range (nmi)	Bearing (degrees)
03:45:15	0.0	23.9	34,000	0.0	2.0	32,000	21.9	0
03:45:30	0.0	25.9	34,000	0.0	4.0	32,000	21.8	0
03:45:45	0.0	27.8	34,000	0.0	6.1	32,000	21.7	0
03:46:00	0.0	29.7	34,000	0.0	8.1	32,000	21.6	0
03:46:15	0.0	31.7	34,000	0.0	10.1	32,000	21.5	0
03:46:30	0.0	33.6	34,000	0.0	12.1	32,000	21.5	0
03:46:45	0.0	35.5	34,000	0.0	14.1	32,000	21.4	0
03:47:00	0.0	37.4	34,000	0.0	16.2	32,000	21.3	0
03:47:15	0.0	39.4	34,000	0.0	18.2	32,000	21.2	0
03:47:30	0.0	41.3	34,000	0.0	20.2	32,000	21.1	0
03:47:45	0.0	43.2	34,000	0.0	22.2	32,000	21.0	0
03:48:00	0.0	45.2	34,000	0.0	24.1	32,196	21.1	0
03:48:15	0.0	47.1	34,000	0.0	25.9	32,393	21.2	0
03:48:30	0.0	49.0	34,000	0.0	27.8	32,591	21.2	0
03:48:45	0.0	50.9	34,000	0.0	29.7	32,789	21.2	0
03:49:00	0.0	52.8	34,000	0.0	31.5	32,988	21.2	0
03:49:15	0.0	54.6	34,000	0.0	33.4	33,188	21.2	0
03:49:30	0.0	56.5	34,000	0.0	35.3	33,388	21.2	0
03:49:45	0.0	58.4	34,000	0.0	37.2	33,590	21.2	0
03:50:00	0.3	60.2	33,799	0.0	39.1	33,802	21.2	1
03:50:15	1.1	61.8	33,564	0.0	40.9	34,028	21.0	3
03:50:30	2.6	63.1	33,328	0.0	42.8	34,253	20.5	7
03:50:45	4.4	63.7	33,093	0.0	44.6	34,480	19.5	13
03:51:00	6.2	63.7	32,860	0.0	46.5	34,707	18.3	20
03:51:15	8.0	63.7	32,626	0.0	48.4	34,936	17.3	28
03:51:30	9.9	63.7	32,392	0.0	50.2	35,166	16.7	36
03:51:45	11.7	63.7	32,158	0.0	52.1	35,396	16.5	45
03:52:00	13.5	63.7	31,925	0.0	54.0	35,627	16.7	54
03:52:15	15.4	63.7	31,690	0.0	55.9	35,859	17.2	63
03:52:30	17.2	63.7	31,455	0.0	57.8	36,000	18.2	71
03:52:45	19.1	63.7	31,220	0.0	59.7	36,000	19.5	78
03:53:00	20.9	63.7	30,985	0.0	61.7	36,000	21.0	84
03:53:15	22.8	63.7	30,748	0.0	63.6	36,000	22.8	90
03:53:30	24.6	63.7	30,512	0.0	65.5	36,000	24.7	94
03:53:45	26.5	63.7	30,276	0.0	67.4	36,000	26.8	98
03:54:00	28.4	63.7	30,040	0.0	69.3	36,000	28.9	101
03:54:15	30.2	63.7	29,804	0.0	71.2	36,000	31.1	104
03:54:30	32.1	63.7	29,567	0.0	73.1	36,000	33.4	106
03:54:45	33.9	63.7	29,330	0.0	75.0	36,000	35.8	108
03:55:00	35.8	63.7	29,092	0.0	76.9	36,000	38.2	110
03:55:15	37.7	63.7	28,855	0.0	78.8	36,000	40.6	112
03:55:30	39.5	63.7	28,617	0.0	80.8	36,000	43.1	113
03:55:45	41.4	63.7	28,380	0.0	82.7	36,000	45.5	115
03:56:00	43.3	63.7	28,141	0.0	84.6	36,000	48.0	116
03:56:15	45.1	63.7	27,903	0.0	86.5	36,000	50.6	117
03:56:30	47.0	63.7	27,664	0.0	88.4	36,000	53.1	118
03:56:45	48.9	63.7	27,426	0.0	90.3	36,000	55.7	119
03:57:00	50.8	63.7	27,186	0.0	92.2	36,000	58.2	119

TABLE E-6. DAY 1, CONDITION 6 NUMERICAL DATA (continued)

Time	Lead X-Track (nmi)	Lead Along Track (nmi)	Lead Altitude (ft)	Climb X-Track (nmi)	Climb Along Track (nmi)	Climb Altitude (ft)	Range (nmi)	Bearing (degrees)
03:57:15	52.7	63.7	26,991	0.0	94.1	36,000	60.8	120
03:57:30	54.5	63.7	26,991	0.0	96.0	36,000	63.4	121
03:57:45	56.4	63.7	26,991	0.0	97.9	36,000	66.0	121
03:58:00	58.3	63.7	26,991	0.0	99.9	36,000	68.6	122
03:58:15	60.2	63.7	26,991	0.0	101.8	36,000	71.2	122
03:58:30	62.1	63.7	26,991	0.0	103.7	36,000	73.9	123
03:58:45	64.0	63.7	26,991	0.0	105.6	36,000	76.5	123
03:59:00	65.9	63.7	26,991	0.0	107.5	36,000	79.1	124
03:59:15	67.8	63.7	26,991	0.0	109.4	36,000	81.7	124
03:59:30	69.7	63.7	26,991	0.0	111.3	36,000	84.4	124
03:59:45	71.6	63.7	26,991	0.0	113.2	36,000	87.0	125
04:00:00	73.4	63.7	26,991	0.0	115.1	36,000	89.7	125
04:00:15	75.3	63.7	26,991	0.0	117.0	36,000	92.3	125
04:00:30	77.2	63.7	26,991	0.0	119.0	36,000	95.0	126
04:00:45	79.1	63.7	26,991	0.0	120.9	36,000	97.6	126
04:01:00	81.0	63.7	26,991	0.0	122.8	36,000	100.3	126
04:01:15	82.9	63.7	26,991	0.0	124.7	36,000	102.9	126
04:01:30	84.8	63.7	26,991	0.0	126.6	36,000	105.6	127
04:01:45	86.7	63.7	26,991	0.0	128.5	36,000	108.2	127

TABLE E-7. DAY 2, CONDITION 1 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
01:24:26	19.2	33,000	0	5	1.2	0.859	500	
01:32:30	19.2	33,000	0	5	1.2	0.859	500	239
01:33:00	19.2	33,000	0	5	1.2	0.859	500	
01:34:00	19.2	33,000	0	5	1.2	0.858	499	
01:34:23	19.2	33,000	0	5	1.2	0.858	499	
01:36:00	17.2	33,000	0	5	1.2	0.859	500	
01:37:00	17.2	33,000	0	5	1.2	0.858	499	
01:37:15	17.0	33,000	0	5	1.2	0.858	499	239
01:38:15	16.2	33,000	0	5	1.2	0.859	500	239
01:39:00	15.8	33,000	0	5	1.2	0.859	500	
01:39:15	15.7	33,000	0	5	1.2	0.858	499	239
01:39:30	15.5	33,000	800	5	1.2	0.858	499	239
01:39:45	15.3	33,083	800	5	1.2	0.852	496	239
01:40:00	15.2	33,270	800	5	1.2	0.851	495	239
01:40:15	15.2	33,471	800	5	1.2	0.849	494	239
01:40:30	15.1	33,673	800	5	1.2	0.848	493	239
01:40:45	15.0	33,872	800	5	1.2	0.847	493	239
01:41:00	15.0	34,076	1000	5	1.2	0.844	489	239
01:41:15	15.0	34,345	1000	5	1.2	0.840	486	239
01:41:30	15.0	34,550	1000	5	1.2	0.836	484	239
01:41:45	15.0	34,813	1000	5	1.2	0.832	482	239
01:42:00	14.9	35,041	900	5	1.2	0.830	478	239
01:42:15	14.9	35,341	900	5	1.2	0.828	477	239
01:42:30	14.9	35,449	800	5	1.2	0.826	476	239
01:42:45	14.9	35,651	800	5	1.2	0.824	475	239
01:43:00	14.9	35,841	800	5	1.2	0.821	473	239
01:43:15	14.9	36,012	800	5	1.2	0.821	471	239
01:43:30	14.9	36,171	800	5	1.2	0.821	471	239
01:43:45	14.9	36,329	700	5	1.2	0.821	471	238
01:44:00	14.9	36,470	600	5	1.2	0.821	471	238
01:44:15	14.9	36,621	600	3	0.7	0.820	471	238
01:44:30	14.9	36,758	600	3	0.7	0.817	469	238
01:44:45	14.9	36,898	400	3	0.7	0.816	468	238
01:45:00	14.9	36,989	0	3	0.7	0.817	469	238
01:45:15	15.0	36,999	0	3	0.7	0.818	469	238
01:45:30	15.0	37,000	0	3	0.7	0.822	472	238

TABLE E-8. DAY 2, CONDITION 2 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
01:53:57	22.0	31,000	0	0	0.0	0.852	500	234
01:58:45	22.0	31,000	0	0	0.0	0.852	500	234
01:59:30	21.8	31,000	0	0	0.0	0.850	499	234
02:00:30	21.8	31,000	0	0	0.0	0.850	499	234
02:01:00	21.8	31,000	0	0	0.0	0.851	499	232
	21.8	31,000	0	0	0.0	0.851	499	232
02:01:15	21.6	31,000	0	0	0.0	0.851	499	232
02:01:45	20.5	31,001	0	0	0.0	0.850	499	232
02:02:00	20.5	31,001	0	0	0.0	0.850	499	232
02:03:00	20.0	31,001	0	0	0.0	0.850	499	232
02:03:30	20.0	31,001	0	0	0.0	0.851	499	232
02:03:45	20.0	31,001	0	0	0.0	0.851	499	232
02:04:15	20.0	31,001	0	0	0.0	0.850	499	232
02:05:45	20.0	31,001	0	0	0.0	0.851	499	232
02:06:00	19.8	31,001	0	0	0.0	0.851	499	232
02:07:00	19.5	31,001	0	0	0.0	0.851	499	232
02:08:00	19.4	31,001	0	0	0.0	0.851	499	232
02:09:00	19.2	31,001	0	0	0.0	0.851	499	232
02:09:27	19.2	31,001	0	0	0.0	0.851	499	232

TABLE E-9. DAY 2, CONDITION 3 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
02:17:15	21.2	34,000	0	0	0.0	0.863	500	46
02:19:30	21.2	34,000	0	0	0.0	0.863	500	46
02:20:45	21.2	34,000	0	0	0.0	0.863	500	46
02:21:00	21.2	34,000	0	0	0.0	0.863	500	46
02:24:00	19.5	34,000	0	0	0.0	0.863	500	46
02:25:00	19.5	34,000	0	0	0.0	0.863	500	46
02:28:15	18.7	34,000	0	0	0.0	0.863	500	46
02:28:30	18.5	34,001	400	0	0.0	0.861	499	46
02:28:45	18.5	34,180	900	0	0.0	0.857	496	46
02:29:00	18.5	34,381	900	0	0.0	0.854	494	46
02:29:15	18.5	34,578	900	0	0.0	0.851	493	46
02:29:30	18.5	34,771	900	0	0.0	0.848	491	46
02:29:45	18.5	34,970	900	0	0.0	0.845	489	47
02:30:00	18.5	35,183	700	0	0.0	0.843	486	47
02:30:15	18.4	35,331	700	0	0.0	0.842	485	47
02:30:30	18.3	35,481	700	0	0.0	0.841	485	47
02:30:45	18.2	35,632	700	0	0.0	0.840	484	47
02:31:00	18.2	35,783	700	0	0.0	0.839	484	47
02:31:15	18.2	35,912	400	0	0.0	0.838	483	47
02:31:30	18.2	36,031	500	0	0.0	0.838	481	47
02:31:45	18.2	36,142	500	0	0.0	0.837	480	47
02:32:00	18.2	36,281	500	0	0.0	0.836	480	47
02:32:15	18.2	36,384	500	0	0.0	0.835	479	47
02:32:30	18.3	36,514	500	0	0.0	0.833	478	47
02:32:45	18.3	36,640	500	0	0.0	0.832	477	47
02:33:00	18.3	36,785	500	0	0.0	0.830	476	47
02:33:15	18.3	36,863	500	0	0.0	0.828	475	47
02:33:30	18.3	37,001	500	0	0.0	0.827	474	47
02:33:45	18.4	37,130	500	0	0.0	0.825	473	47
02:34:00	18.4	37,261	500	0	0.0	0.824	473	47
02:34:15	18.4	37,381	500	0	0.0	0.822	472	47
02:34:30	18.5	37,541	500	0	0.0	0.820	470	47
02:34:45	18.6	37,626	500	0	0.0	0.818	469	47
02:35:00	18.7	37,736	500	0	0.0	0.817	469	47
02:35:15	18.7	37,871	500	0	0.0	0.815	467	47
02:35:30	18.8	37,979	0	0	0.0	0.814	467	47
02:35:45	18.9	37,999	0	0	0.0	0.816	468	47
02:36:00	19.0	38,000	0	0	0.0	0.819	470	47

TABLE E-10. DAY 2, CONDITION 4 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
02:46:51	19.0	32,000	0	0	0.0	0.827	483	46
02:50:00	19.0	32,000	0	0	0.0	0.827	483	46
02:51:15	19.0	32,000	0	0	0.0	0.827	483	46
02:51:30	19.0	31,999	0	0	0.0	0.828	474	46
02:57:00	18.2	32,000	0	0	0.0	0.828	472	46
02:57:00	18.2	32,000	0	0	0.0	0.826	483	46
02:57:15	17.3	32,000	0	0	0.0	0.826	483	46
02:57:30	17.3	32,000	0	0	0.0	0.827	483	47
02:57:45	17.2	32,000	0	0	0.0	0.826	483	47
02:58:00	17.2	32,000	0	0	0.0	0.826	483	47
02:58:15	17.1	32,000	0	0	0.0	0.826	483	47
02:58:30	17.0	32,100	900	0	0.0	0.823	481	47
02:58:45	16.9	32,300	900	0	0.0	0.824	481	47
02:59:00	16.8	32,500	900	0	0.0	0.826	483	47
02:59:15	16.7	32,700	900	0	0.0	0.827	483	47
02:59:30	16.6	32,900	900	0	0.0	0.826	483	47
02:59:45	16.4	33,150	900	0	0.0	0.829	482	47
03:00:00	16.2	33,350	900	0	0.0	0.829	482	47
03:00:15	16.1	33,600	900	0	0.0	0.828	482	47
03:00:30	16.0	33,800	900	0	0.0	0.827	481	47
03:00:45	16.0	34,050	900	0	0.0	0.826	478	47
03:01:00	15.9	34,300	900	0	0.0	0.824	477	47
03:01:15	15.9	34,450	900	0	0.0	0.824	477	47
03:01:30	15.9	34,650	800	0	0.0	0.824	477	47
03:01:45	15.8	34,850	800	0	0.0	0.824	477	47
03:02:00	15.8	35,050	800	0	0.0	0.825	476	47
03:02:15	15.7	35,200	800	0	0.0	0.825	476	47
03:02:30	15.6	35,400	700	0	0.0	0.825	476	47
03:02:45	15.6	35,500	700	0	0.0	0.825	476	47
03:03:00	15.6	35,700	700	0	0.0	0.825	476	47
03:03:15	15.6	35,800	500	0	0.0	0.826	476	47
03:03:30	15.6	35,900	500	0	0.0	0.826	476	47
03:03:45	15.6	36,000	0	0	0.0	0.826	474	47
03:04:00	15.6	36,000	0	0	0.0	0.826	479	47

TABLE E-11. DAY 2, CONDITION 5 NUMERICAL DATA

Time	Range (nmi)	Climb Aircraft Altitude (ft)	Climb Rate (ft/sec)	Bearing Angle (degrees)	Lateral Deviation (nmi)	Speed (Mach)	Ground Speed (knots)	Heading (degrees)
03:19:00	16.2	33,000	0	0	0.0	0.861	501	219
	16.2	33,000	0	0	0.0	0.861	501	219
03:21:00	16.2	33,000	0	0	0.0	0.861	501	219
03:22:00	15.9	33,000	0	0	0.0	0.861	501	219
03:24:00	15.7	33,000	0	0	0.0	0.861	501	219
03:24:15	15.5	33,000	0	0	2.5	0.861	501	219
03:24:30	15.3	33,000	0	0	2.5	0.861	501	219
03:24:45	15.2	33,000	0	0	2.5	0.861	501	219
03:25:00	15.0	33,000	0	10	2.5	0.861	501	221
03:25:30	14.8	33,000	0	10	2.5	0.861	501	216
03:25:45	14.6	33,000	0	0	2.4	0.861	501	216
03:26:00	14.6	33,000	0	0	2.4	0.861	501	216
03:26:15	14.6	33,000	0	0	2.4	0.862	501	216
03:27:00	14.5	33,000	0	0	2.4	0.862	501	216
03:28:00	13.2	33,000	0	0	2.3	0.861	501	216

TABLE E-12. DAY 2, CONDITION 6 NUMERICAL DATA

Time	Lead X-Track (nmi)	Lead Along Track	Lead Altitude (ft)	Climb X-Track (nmi)	Climb Along Track	Climb Altitude (ft)	Range (nmi)	Bearing (degrees)
03:42:15	0.0	24.9	34,000	0.0	2.0	32,000	22.9	0
03:42:30	0.0	26.9	34,000	0.0	4.0	32,000	22.8	0
03:42:45	0.0	28.8	34,000	0.0	6.1	32,000	22.7	0
03:43:00	0.0	30.7	34,000	0.0	8.1	32,000	22.6	0
03:43:15	0.0	32.7	34,000	0.0	10.1	32,000	22.5	0
03:43:30	0.0	34.6	34,000	0.0	12.1	32,000	22.5	0
03:43:45	0.0	36.5	34,000	0.0	14.1	32,000	22.4	0
03:44:00	0.0	38.4	34,000	0.0	16.2	32,000	22.3	0
03:44:15	0.0	40.4	34,000	0.0	18.2	32,000	22.2	0
03:44:30	0.0	42.3	34,000	0.0	20.2	32,000	22.1	0
03:44:45	0.0	44.2	34,000	0.0	22.2	32,000	22.0	0
03:45:00	0.0	46.2	34,000	0.0	24.3	32,000	21.9	0
03:45:15	0.0	48.1	34,000	0.0	26.3	32,227	21.8	0
03:45:30	0.0	50.0	34,000	0.0	28.3	32,454	21.7	0
03:45:45	0.0	51.9	34,000	0.0	30.3	32,683	21.6	0
03:46:00	0.0	53.7	34,000	-0.0	32.3	32,912	21.4	0
03:46:15	0.0	55.6	34,000	-0.2	34.3	32,963	21.3	0
03:46:30	0.3	57.4	33,764	-0.4	36.3	33,014	21.1	2
03:46:45	1.3	59.0	33,527	-0.7	38.3	33,065	20.8	6
03:47:00	2.8	60.1	33,292	-1.1	40.2	33,115	20.2	11
03:47:15	4.6	60.6	33,058	-1.3	42.2	33,360	19.3	18
03:47:30	6.5	60.6	32,824	-1.4	44.2	33,611	18.3	26
03:47:45	8.3	60.6	32,591	-1.3	46.1	33,858	17.4	34
03:48:00	10.2	60.6	32,356	-1.2	48.1	34,103	17.0	42
03:48:15	12.0	60.6	32,123	-1.1	50.0	34,350	16.9	51
03:48:30	13.8	60.6	31,889	-1.0	52.0	34,597	17.2	60
03:48:45	15.7	60.6	31,654	-0.9	53.9	34,845	17.9	68
03:49:00	17.5	60.6	31,419	-0.8	55.9	35,094	19.0	76
03:49:15	19.4	60.6	31,184	-0.7	57.9	35,345	20.3	82
03:49:30	21.2	60.6	30,948	-0.6	59.9	35,595	21.9	88
03:49:45	23.1	60.6	30,712	-0.5	61.9	35,846	23.6	93
03:50:00	24.9	60.6	30,476	-0.4	63.9	36,002	25.5	97
03:50:15	26.8	60.6	30,240	-0.3	65.8	36,002	27.6	101
03:50:30	28.6	60.6	30,004	-0.2	67.8	36,002	29.7	104
03:50:45	30.5	60.6	29,768	-0.1	69.8	36,002	31.9	107
03:51:00	32.4	60.6	29,531	0.0	71.8	36,002	34.2	109
03:51:15	34.2	60.6	29,294	0.0	73.8	36,002	36.6	111
03:51:30	36.1	60.6	29,056	0.0	75.8	36,002	38.9	113
03:51:45	38.0	60.6	28,818	0.0	77.7	36,002	41.3	114
03:52:00	39.8	60.6	28,581	0.0	79.7	36,002	43.8	116
03:52:15	41.7	60.6	28,343	0.0	81.7	36,002	46.2	117
03:52:30	43.6	60.6	28,105	0.0	83.7	36,002	48.7	118
03:52:45	45.4	60.6	27,867	0.0	85.7	36,002	51.2	119
03:53:00	47.3	60.6	27,628	0.0	87.6	36,002	53.8	120
03:53:15	49.2	60.6	27,389	0.0	89.6	36,002	56.3	121
03:53:30	51.1	60.6	27,150	0.0	91.6	36,002	58.8	122
03:53:45	52.9	60.6	26,991	0.0	93.6	36,002	61.4	122
03:54:00	54.8	60.6	26,991	0.0	95.6	36,002	64.0	123
03:54:15	56.7	60.6	26,991	0.0	97.6	36,002	66.6	124

TABLE E-12. DAY 2, CONDITION 6 NUMERICAL DATA (continued)

Time	Lead X-Track (nmi)	Lead Along Track	Lead Altitude (ft)	Climb X-Track (nmi)	Climb Along Track	Climb Altitude (ft)	Range (nmi)	Bearing (degrees)
03:54:30	58.6	60.6	26,991	0.0	99.5	36,002	69.1	124
03:54:45	60.5	60.6	26,991	0.0	101.5	36,002	71.7	125
03:55:00	62.4	60.6	26,991	0.0	103.5	36,002	74.3	125
03:55:15	64.3	60.6	26,991	0.0	105.5	36,002	76.9	126
03:55:30	66.2	60.6	26,991	0.0	107.5	36,002	79.6	126
03:55:45	68.1	60.6	26,991	0.0	109.5	36,002	82.2	126
03:56:00	70.0	60.6	26,991	0.0	111.4	36,002	84.8	127
03:56:15	71.9	60.6	26,991	0.0	113.4	36,002	87.4	127
03:56:30	73.7	60.6	26,991	0.0	115.4	36,002	90.0	127
03:56:45	75.6	60.6	26,991	0.0	117.4	36,002	92.7	128
03:57:00	77.5	60.6	26,991	0.0	119.4	36,002	95.3	128
03:57:15	79.4	60.6	26,991	0.0	121.3	36,002	97.9	128
03:57:30	81.3	60.6	26,991	0.0	123.3	36,002	100.5	129
03:57:45	83.2	60.6	26,991	0.0	125.3	36,002	103.2	129
03:58:00	85.1	60.6	26,991	0.0	127.3	36,002	105.8	129
03:58:15	87.0	60.6	26,991	0.0	129.3	36,002	108.5	129
03:58:30	88.9	60.6	26,991	0.0	131.3	36,002	111.1	129
03:58:45	90.8	60.6	26,991	0.0	133.2	36,002	113.7	130

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